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TECHNICAL REPORT

Collection and Analysis of Ground Truth Infrasound Data in Kazakhstan and Russia

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May 2006

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14. ABSTRACT
Our final report is in two parts. Part one is a text of a draft manuscript prepared for publication, titled "Seismic and Infrasound Observations at Borovoye, Northern Kazakhstan." In this paper, we have analyzed seismic and infrasound signals from large mining explosions in Northern Kazakhstan - Ekibaastuz (distance=380 km) and Kokchetav (distance=74 km). Detection of infrasound signals at these distance ranges at mid-latitude (50 degrees N), suggests the existence of a tropospheric duct and a modified sound speed profile, which has a fast troposphere and an elevated stratospheric lid. Part two is a report titled "Ground Truth Data of Large Mining Explosions in Altay-Sayan Region, Southwestern Siberia, Russia." We report on the ground truth data of large mining explosions in Kuzbass and Abakan regions. We acquired GT10 quality ground truth data for 424 explosions (location, time, seismic magnitude, yield in tons) during 1999-2000 and associated waveform data from a broadband station Yeltsovka (ELT) which we deployed during 1998-1999 in the region.

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Preface

We thank Drs. Vitaly Khalturin and A. Yemanov for providing us the ground truth information from Kuzbass and Abakan industrial mining area. Staff at Altay-Sayan Experimental and Methodical Seismological Expedition (ASEMSE), Siberian Branch of Russian Academy of Sciences in Novosibirsk, Russia has help us to acquire digital seismic data from Yeltsovka (ELT).

We thank the personnel of the Kurchatov and Borovoye Geophysical Observatories, National Nuclear Center, Republic of Kazakstan for their support in acquiring high quality seismic and infrasound data.

CONVERSION TABLE

Conversion Factors for U.S. Customary to metric (SI) units of measurement.

MULTIPLY → BY → TO GET
TO GET ← BY ← DIVIDE

angstrom	1.000 000 x E -10	meters (m)
atmosphere (normal)	1.013 25 x E +2	kilo pascal (kPa)
bar	1.000 000 x E +2	kilo pascal (kPa)
barn	1.000 000 x E -28	meter^2 (m^2)
British thermal unit (thermochemical)	1.054 350 x E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical/cm^2)	4.184 000 x E -2	mega joule/m^2 (MJ/m^2)
curie	3.700 000 x E +1	*giga bacquerel (GBq)
degree (angle)	1.745 329 x E -2	radian (rad)
degree Fahrenheit	$t_k = (t^o f + 459.67)/1.8$	degree kelvin (K)
electron volt	1.602 19 x E -19	joule (J)
erg	1.000 000 x E -7	joule (J)
erg/second	1.000 000 x E -7	watt (W)
foot	3.048 000 x E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 x E -3	meter^3 (m^3)
inch	2.540 000 x E -2	meter (m)
jerk	1.000 000 x E +9	joule (J)
joule/kilogram (J/kg) radiation dose absorbed	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 x E +3	newton (N)
kip/inch^2 (ksi)	6.894 757 x E +3	kilo pascal (kPa)
ktap	1.000 000 x E +2	newton-second/m^2 (N-s/m^2)
micron	1.000 000 x E -6	meter (m)
mil	2.540 000 x E -5	meter (m)
mile (international)	1.609 344 x E +3	meter (m)
ounce	2.834 952 x E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 x E -1	newton-meter (N-m)
pound-force/inch	1.751 268 x E +2	newton/meter (N/m)
pound-force/foot^2	4.788 026 x E -2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535 924 x E -1	kilogram (kg)
pound-mass-foot^2 (moment of inertia)	4.214 011 x E -2	kilogram-meter^2 (kg-m^2)
pound-mass/foot^3	1.601 846 x E +1	kilogram-meter^3 (kg/m^3)
rad (radiation dose absorbed)	1.000 000 x E -2	**Gray (Gy)
roentgen	2.579 760 x E -4	coulomb/kilogram (C/kg)
shake	1.000 000 x E -8	second (s)
slug	1.459 390 x E +1	kilogram (kg)
torr (mm Hg, 0° C)	1.333 22 x E -1	kilo pascal (kPa)

*The bacquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (GY) is the SI unit of absorbed radiation.

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Section 1

Executive Summary

Our Final Report is in two parts. Part one is a text of a draft manuscript prepared for publication, titled "Seismic and Infrasound Observations at Borovoye, Northern Kazakstan." In this paper, we have analyzed seismic and infrasound signals from large mining explosions in northern Kazakstan –Ekibastuz (Δ=380 km) and Kokchetav (Δ=74 km). Detection of infrasound signals at these distance ranges at mid-latitude (50°N), suggests existence of a tropospheric duct and a modified sound speed profile, which has a fast troposphere and an elevated stratospheric lid.

Part two is a report titled "Ground Truth Data of Large Mining Explosions in Altay-Sayan Region, Southwestern Siberia, Russia". We report on the ground truth data of large mining explosions in Kuzbass and Abakan regions. We acquired GT10 quality ground truth data for 424 explosions (location, time, seismic magnitude, yield in tons) during 1999–2000 and associated waveform data from a broadband station Yeltsovka (ELT) which we deployed during 1998–1999 in the region.

Section 2

Seismic and Infrasound Observations at Borovoye, Northern Kazakstan

2.1 Introduction

In order to meet the monitoring requirements of nuclear test ban treaties, such as the Comprehensive Test Ban Treaty (CTBT) or the Nuclear Non-Proliferation Treaty (NNPT), three technologies - seismic, hydroacoustic, and infrasonic - are employed to detect acoustic and seismic waves produced by nuclear and large industrial explosions detonated on land, in the sea, and in the air. While seismic and hydroacoustic technologies are sufficiently evolved to support the monitoring needs of the CTBT or the NNPT, in its current state, infrasonic technology is not. There are several reasons why development of the infrasound component lags behind the other two. Chief among these is the greater difficulty encountered in recording acoustic signals in the atmosphere versus in the ocean or in the earth. The greater levels of cultural and wind noise in the atmosphere hinder reliable infrasonic detection.

Detection can be improved by utilizing inlet hose or pipe arrays, designed to decorrelate wind noise by spatially filtering the input signal. Furthermore, temperatures in the atmosphere vary on time scales of hours to months, and wind speeds (up to 100 m/s) are a significant fraction of the average sound speed ($\sim$330 m/s). The result is that the acoustic propagation channels in the atmosphere are highly variable. This variability must be quantified for infrasonic monitoring to meet the needs of the CTBT or the NNPT.

During December 1999 through February 2000, we carried out infrasound observations at the Borovoye Geophysical Observatory (BRV) in northern Kazakstan using available microphones coupled with noise reduction systems in order to address some of the infrasound monitoring issues outlined above. The Borovoye Observatory (Figure 1) is an ideal site for research on infrasound and on the application of synergistic (seismic and acoustic) methods of event discrimination as it operates both a 4-element three-component, broadband seismic array and an infrasound array (Figure 1b), and because of its close proximity to several large mining operations (Figure 1). In addition, conditions appear to be favorable for long-range infrasound propagation in Kazakstan, where infrasound signals have been detected out to 2,000 km distance [Al'Perovich et al., 1985; Hagerty et al., 2002].

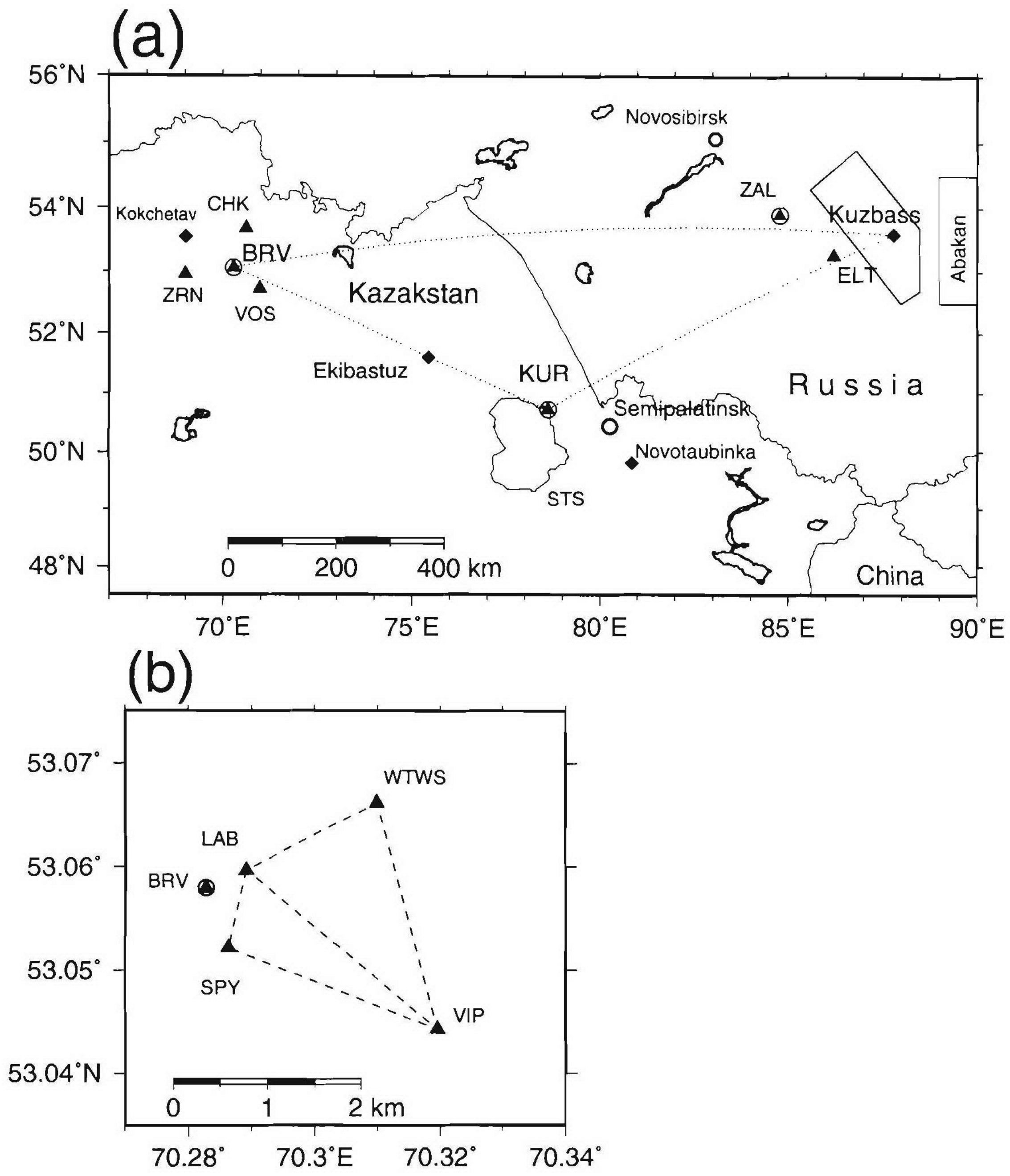

Figure 1: (a) Map of Kazakstan and southwestern Siberia showing location of broadband seismic stations (solid triangle), active mining areas (diamond), and the Kurchatov (KUR) and Borovoye (BRV) Geophysical Observatories, where seismic and infrasound monitoring systems are deployed. Kuzbass and Abakan mining regions in Siberia are indicated, (b) infrasound system configuration of Borovoye array.

2.2 Borovoye Infrasound Array.

We deployed 4-element infrasound array around Borovoye Geophysical Observatory in northern Kazakstan (Figure 1). Two types of noise reduction configuration were utilized in this study: 1) six, 70 m long underground pipes extending radially from a central chamber and referred to as "Spider"; and 2) six, 50 m long soacker hoses extending radially from a central chamber at the sensor manifold. We presume that a spider system, which were constructed during the Soviet era, were designed to be functional during the severe local winters, when snow covers the ground for five months each year and prohibits the use of conventional plastic hoses. Transfer functions for these systems are not yet determined.

A type of capacitor microphone (Globe) has been utilized with the pipe arrays described above. Globe microphones have been used widely in infrasound research for many years and their broadband response is well known (e.g., Donn and Posmentier [1968]). The analog signal from the sensors are digitized by a 24-bit A/D system and recorded continuously at 20 samples/s. Infrasound signals in the frequency band of 0.8-5 Hz have been used for detection, and array processing.

Several large mines in the region generate explosions that are routinely detected seismically and, in some cases, are also detected with infrasound. The mines range in distance from 80 to 750 km from the infrasound array.

2.3 Presumed Mining Blasts from Ekibastuz Region

Ekibastuz region, located about 380 km southeast of the Borovoye infrasound array, is the primary coal mining area in northern Kazakstan. The mining area comprises a number of open pits and covers an approximately 160 km^2 area, between 51.63°– 51.75°N and 75.36°– 75.47°E with a center at about (51.67N, 75.40E) as determined by the local map as well as satellite photographs [Thurber et al., 1990].

The Ekibastuz coal mines, regularly produces 2–3 seismic detections per day. During December, 1999 through February, 2000, 161 presumed mining blasts from Ekibastuz area were detected by the seismic array. However, associated infrasonic detections are found for 11 events or roughly 7% of the seismic detections. The location and origin time of each event were determined from the seismic array and are listed in Table 1. The $S - P$ time for these events vary between 45 and 50 s, averaging about 48 s. The average infrasound travel time is about 1157 s at the reference site VIP, which corresponds to an apparent group velocity of 330 m/s (Figure 2; Table 1).

Mining blasts at Ekibastuz occur more or less same time of the day throughout the year. Comparison of timing of mining blasts during November, 1999 through February, 2000 from Ekibastuz region indicates that majority of mining blasts occur during the afternoon, between 3 and 4 p.m. local time (between 08:00 - 09:00 UTC), although mining blasts may stretch out between 10 a.m. and 6 p.m. About 75% of the mining blast from Ekibastuz mining area occurred between 3 and 4 pm local time.

The infrasound wavetrain generated by Ekibastuz explosions can be classified into two different types. The first type, shown in Figure 3, consists of 1 or 2 simple pulses, with travel times of approximately 1157 s with respect to the seismically estimated origin time. The second type of the waveforms show multiple pulses about 10-12 s duration (Figure 3).

The travel time of the first arrival exhibits some variation and probably reflects varying atmospheric conditions such as transient propagation ducts. This is discussed further in the next section. These events were originated from a small mining area (about 12×13 km^2), and propagated along a similar trajectory. Hence, the events have a common path and as such the path effect may not produce waveforms with varying shape and duration between events, at least within an hour of time difference (compare infrasonic signals from events on 01/21/2000 at 07:54 and 08:55; Figure 3). Also, for each event, similar waveform patterns occur at all stations of the array located over a distance range of 2 to 3 km (Figure 4 & 5). Hence, receiver effect also may not be a likely factor in shaping these two groups of waveforms. It is more likely that excitation of infrasound wavefields at source as well as directivity of the blasts may shape the these different waveforms.

An array beam has been obtained by slant stacking the traces with a 2 s moving window and locating the maximum power within each window. Maximum power occurs when the traces are aligned with a horizontal phase velocity of 0.31 to 0.36 km/s and a back-azimuth between 104°and 107°(Table 1 and Figure 4 & 5). The back azimuth for the given location at Ekibastuz is 113°from Borovoye infrasound array. There may be several possible reasons for this

discrepancy. The cross-winds in the upper atmosphere can greatly alter the apparent azimuth of infrasound signals.

Table 1: Seismic and infrasound observations of explosions from Kazakstan mining areas[1]

		Seismic			Infrasonic		
		TT (s)			TT (s)	Beam forming	
Date	Time	*P*	*S-P*	BAZ (°)		BAZ (°)	V (m/s)
Ekibastuz (51.67°N, 75.40°E)							
12-15-1999	09:20:44.2	54.4	47.3	112.9	1154.5	106.9	310
12-17-1999	08:05:30.3	66.4	48.1	112.9	1174.9	104.6	320
12-17-1999	08:41:48.9	63.3	48.1	112.9	1168.2	104.6	320
12-27-1999	07:46:40.3	55.2	45.9	112.9	1195.1	106.4	320
01-18-2000	09:46:12.1	51.3	49.5	112.9	1210.2	-	-
01-21-2000	07:51:22.1	53.8	44.3	112.9	1110.5	108.3	310
01-21-2000	07:54:03.5	55.4	48.5	112.9	1080.8	116.6	370
01-21-2000	08:55:53.0	55.3	48.8	112.9	1164.3	104.6	320
01-21-2000	09:19:25.5	55.3	-	112.9	1161.5	104.6	320
01-21-2000	10:15:38.0	56.5	46.0	112.9	1165.5	104.6	320
01-28-2000	10:07:18.6	51.0	47.1	112.9	1150.4	-	-
Kokchetav (53.6°N, 69.7°E)							
12-13-1999	10:43:24.8	10.7	8.9	325.8	216.8	322.1	330
12-15-1999	09:57:14.2	11.6	8.5	325.8	219.0	309.5	340
12-29-1999	09:21:35.1	12.2	-	325.8	219.1	311.4	340
01-28-2000	10:43:02.6	12.0	8.7	325.8	228.0	326.9	310
Ice mining near Borovoye							
01-27-2000	10:07:21.3	2.8	2.1	215.0	36.1	217.8	330

[1] TT= travel time; BAZ= back azimuth; V= velocity.

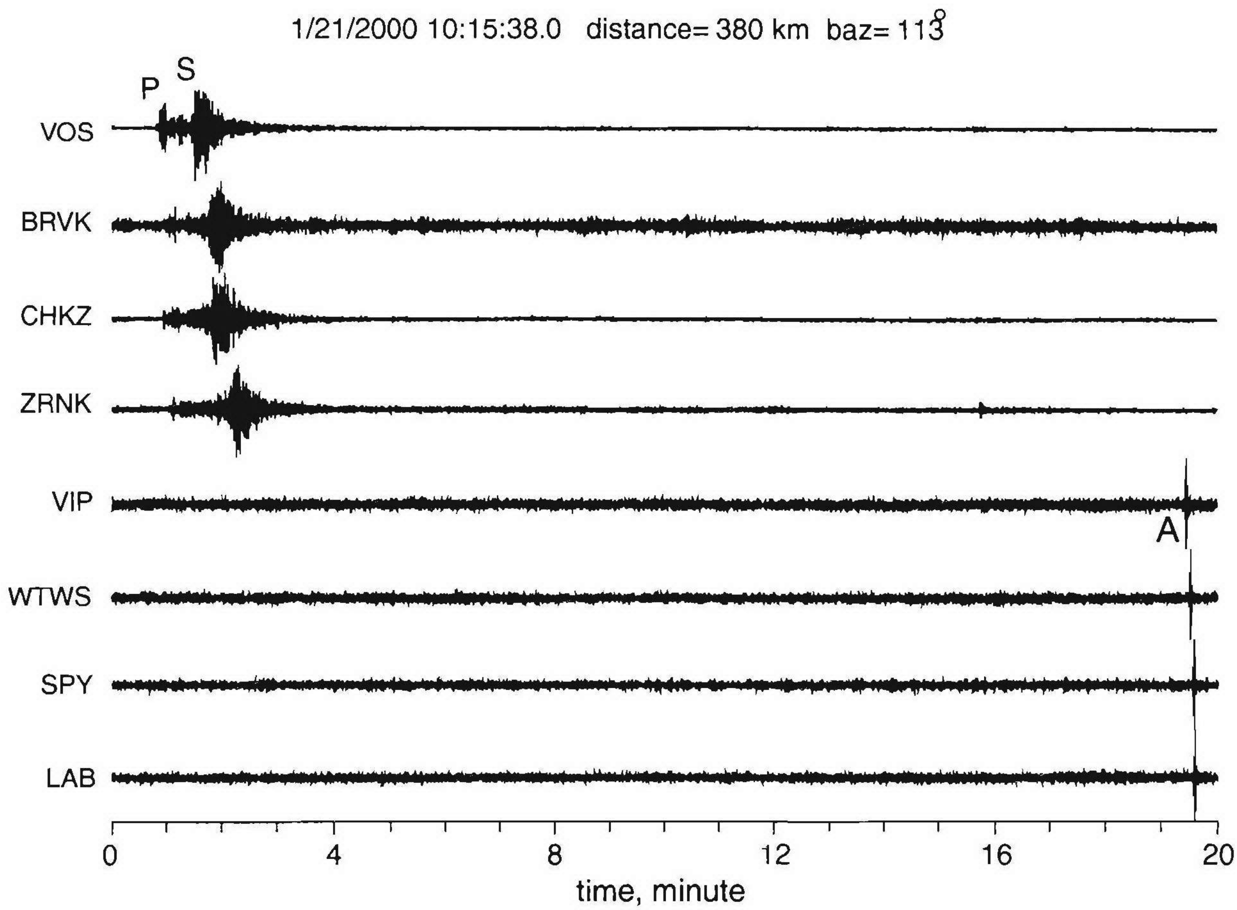

Figure 2: Vertical-component seismic records (*top four traces*) at broadband seismographic stations around Borovoye from the event on 01/21/2000 at 10:15 and corresponding infrasound records (*bottom four traces*) from 4-element array in Borovoye. The P-wave travel time for this event is 56.5 s, and $S - P$ time is 46 s. Infrasound travel time is about 1161 s and are marked as "A" on the trace from the reference station VIP. The data are bandpass filtered between 0.8 and 5 Hz.

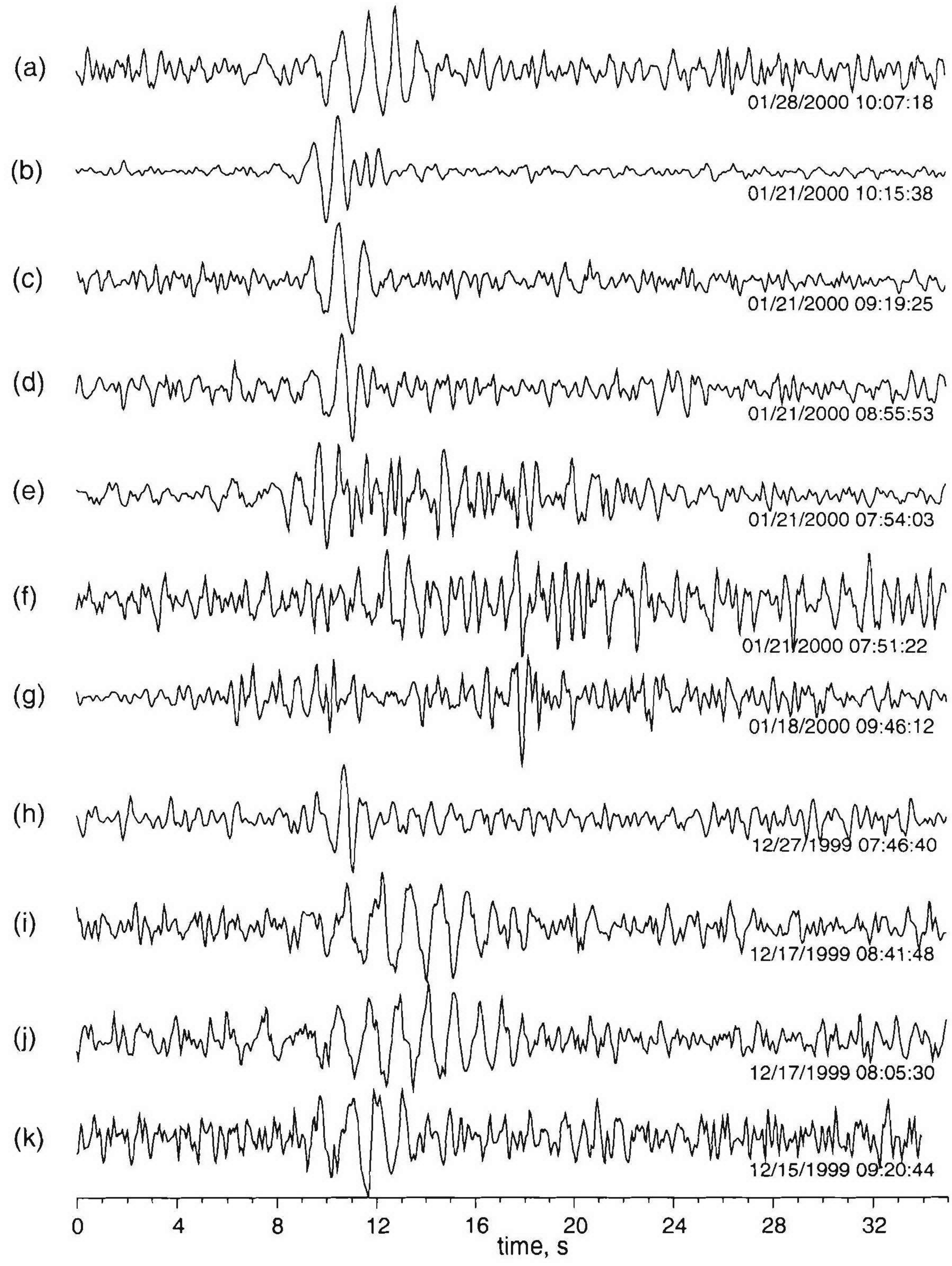

Figure 3: Infrasound signals recorded at the reference site VIP from 11 presumed mining blasts at Ekibastuz. For some events, signals are simple and with pulses 2–3 s duration. For others, signals show multiple pulses of about 10–12 s duration. Signals are bandpass filtered between 0.8 and 5 Hz.

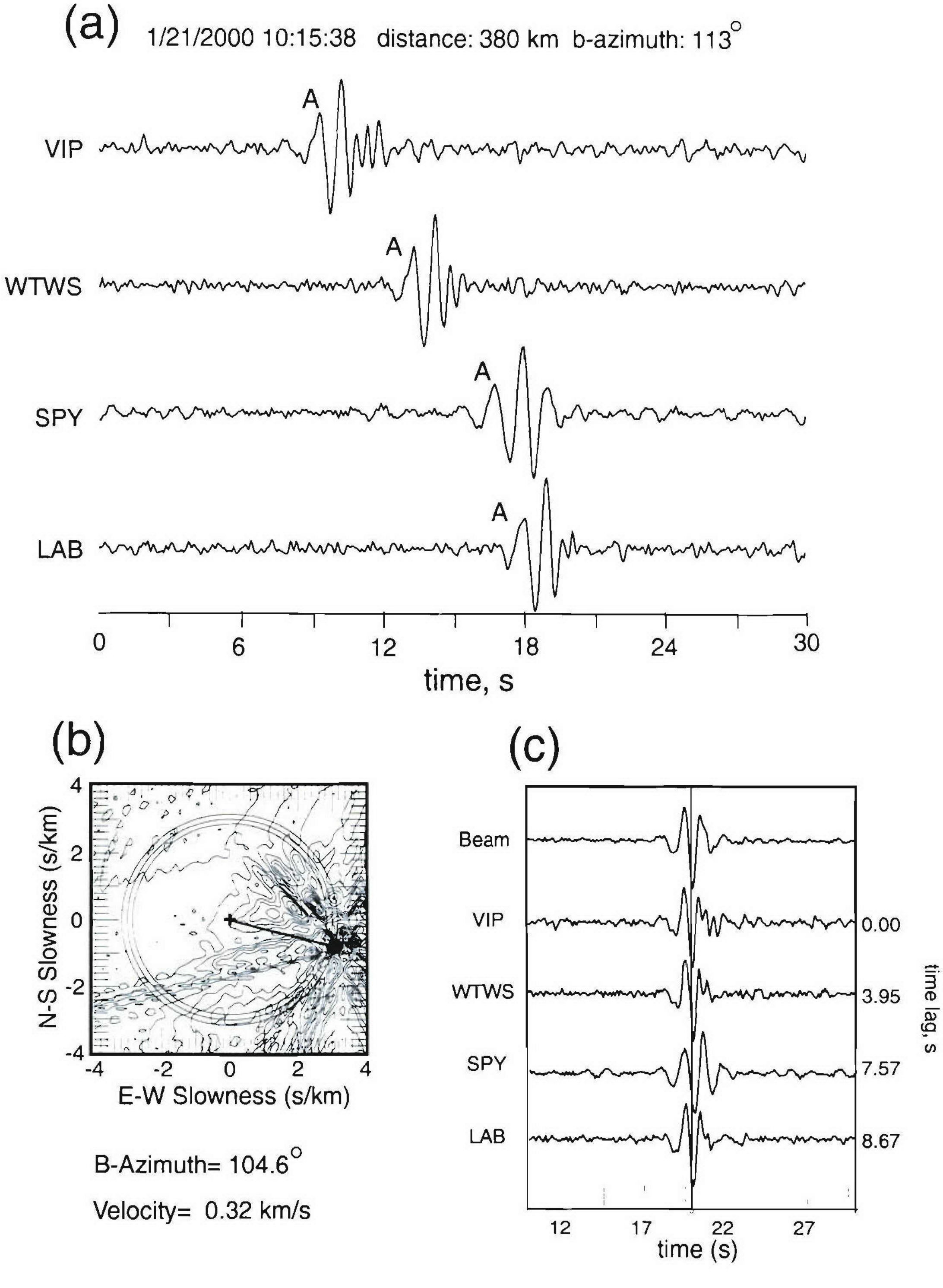

Figure 4: (a) Infrasound signals from a Ekibastuz explosion recorded by Borovoye infrasound array. Signals are bandpass filtered between 0.8 and 5 Hz. (b) contour plot of beam power obtained by slant-stacking infrasound traces at different slownesses. Maximum beam power is obtained for phase velocity=0.32 km/s and back azimuth= 104.6°. (c) Expanded view of array beam trace (*top trace*) and corresponding infrasound traces aligned for the array beam. Time lag at each station relative to the reference station (VIP) is written at the end of each trace.

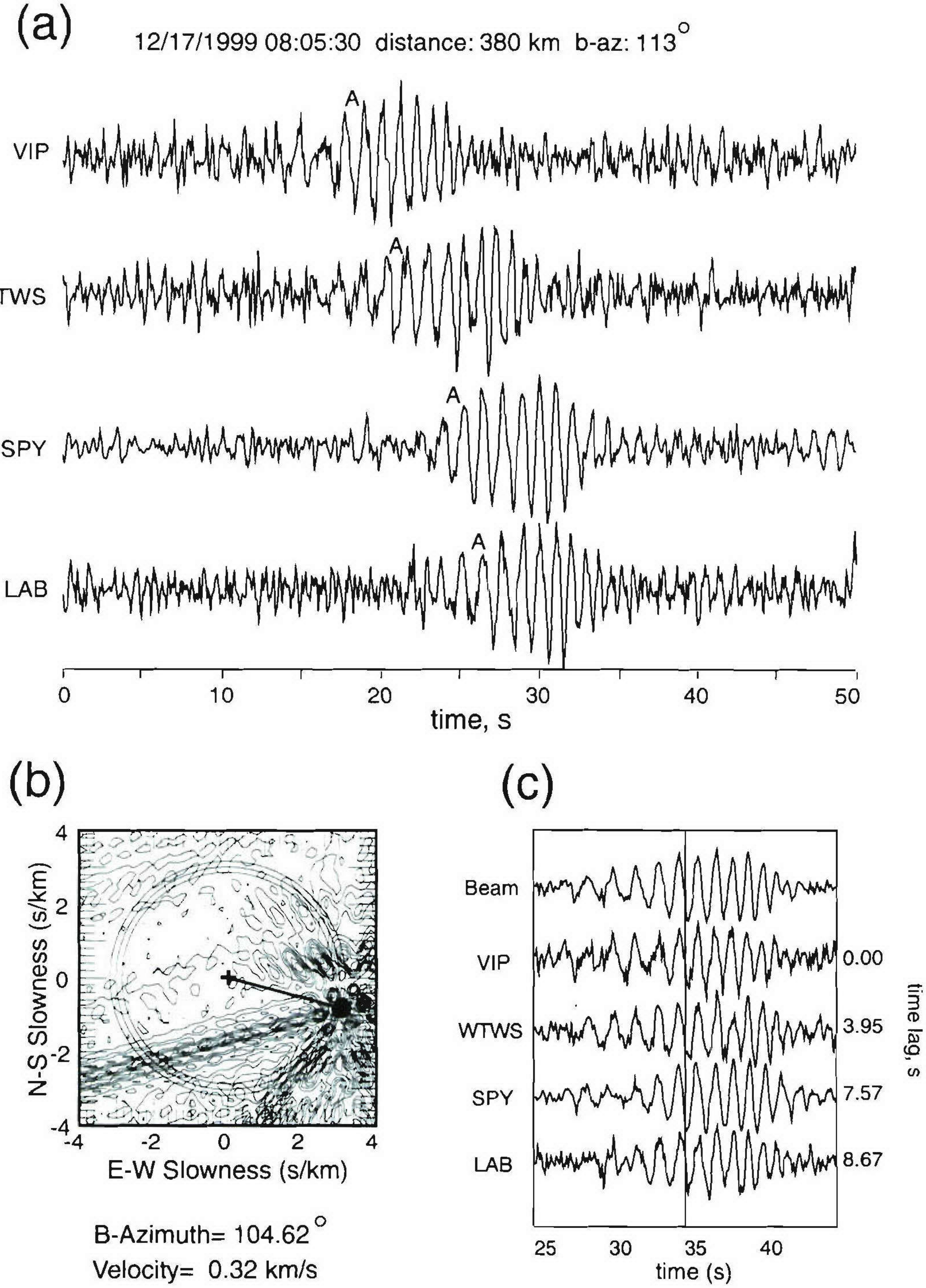

Figure 5: (a) Infrasound signals from a Ekibastuz explosion recorded by Borovoye infrasound array. Signals are bandpass filtered between 0.8 and 5 Hz. (b) contour plot of beam power. Maximum beam power is obtained for phase velocity=0.32 km/s and back azimuth= 104.6°. (c) Expanded view of array beam trace (*top trace*) and corresponding infrasound traces aligned for the array beam. Time lag at each station relative to the reference station (VIP) is written at the end of each trace.

2.4 Presumed Mining Blasts from Kokchetav Region

During December 1999 through February 2000, we recorded 28 seismic events from Kokchetav mining region in northern Kazakstan, of which four (14%) events are also detected by infrasound sensors. Seismic and infrasound records from the event on 01/28/2000, 10:43 are shown in Figure 6. Kokchetav mining region is located about 70 km northwest of the infrasound array (back azimuth=326°; Figure 1). The events are clustered at around a central location at 53.6°N and 69.7°E.

The average $S - P$ time is approximately 8.7 s at BRVK station. The average infrasound travel time is about 220 s at the reference site, VIP station, giving an apparent group velocity of about 318 m/s. The infrasound wavetrains from these events show signals with various frequency contents and complexities, although the distance range is only about 70 km. For instance, the infrasound signal from the event on 01/28/2000 (10:43) is relatively simpler than the signals from the event on 12/13/1999 (10:43) (see Figure 7).

However, observed infrasonic waveforms from particular event at all stations of the array are similar to each other. Hence, each event generated distinct infrasound signals. This observation is comparable to the infrasound signals from Ekibastuz events recorded at Borovoye. This must be due to source excitation, since the propagation paths from each event to the array sites are similar.

Beam traces calculated for these events show that the predicted phase velocity ranges between 310 and 340 m/s, while the back azimuth ranges between 309°and 326°(Figure 8). The nominal back azimuth from the array to these Kokchetav events is about 326°.

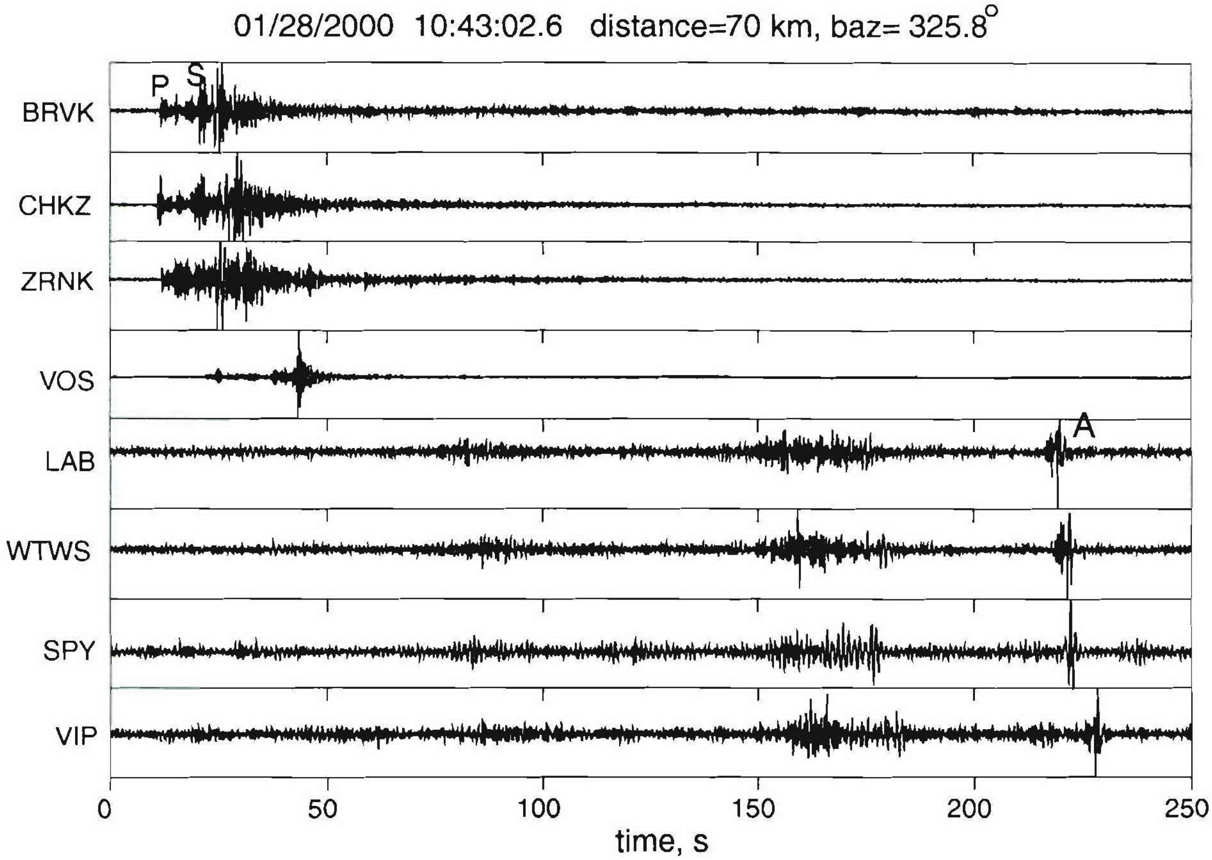

Figure 6: Seismic records (*top four traces*) and corresponding infrasound records (*bottom four traces*) from a presumed mining explosion from Kokchetav area on 01/28/2000 at 10:43. Infrasound arrivals are marked by "A". Signals are bandpass filtered between 0.8 and 5 Hz.

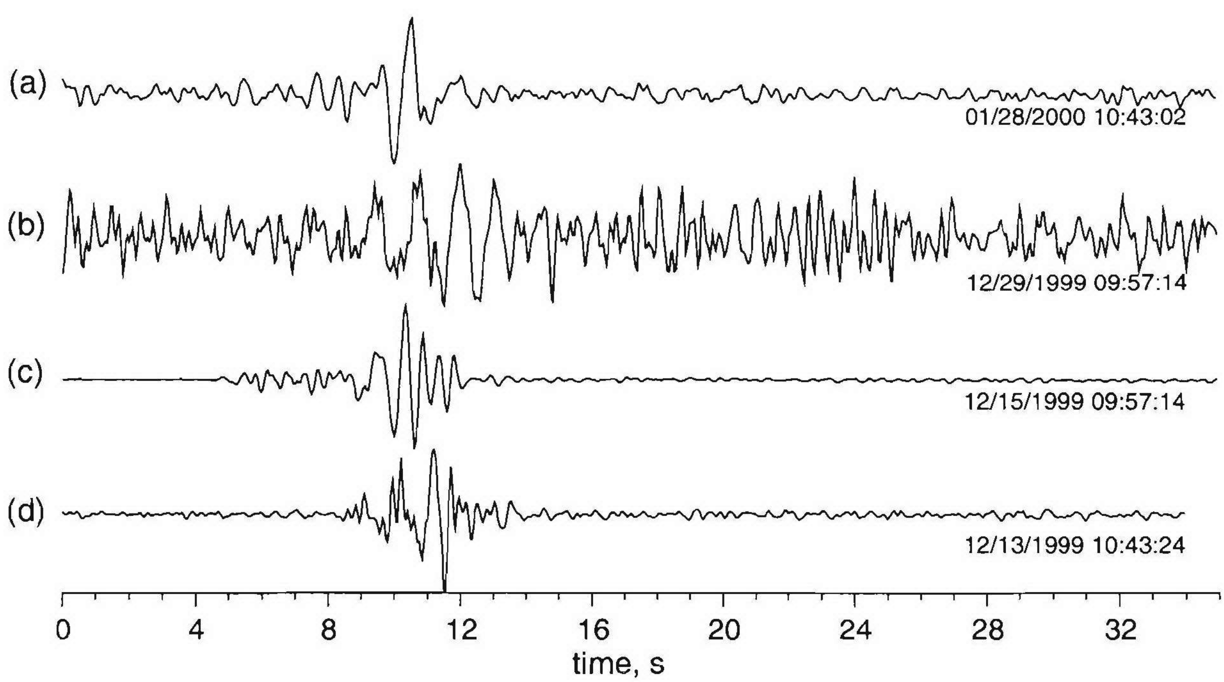

Figure 7: Infrasound records at the reference station VIP, from four events at Kokchetav area. Notice distinctly different frequency contents of the signals.

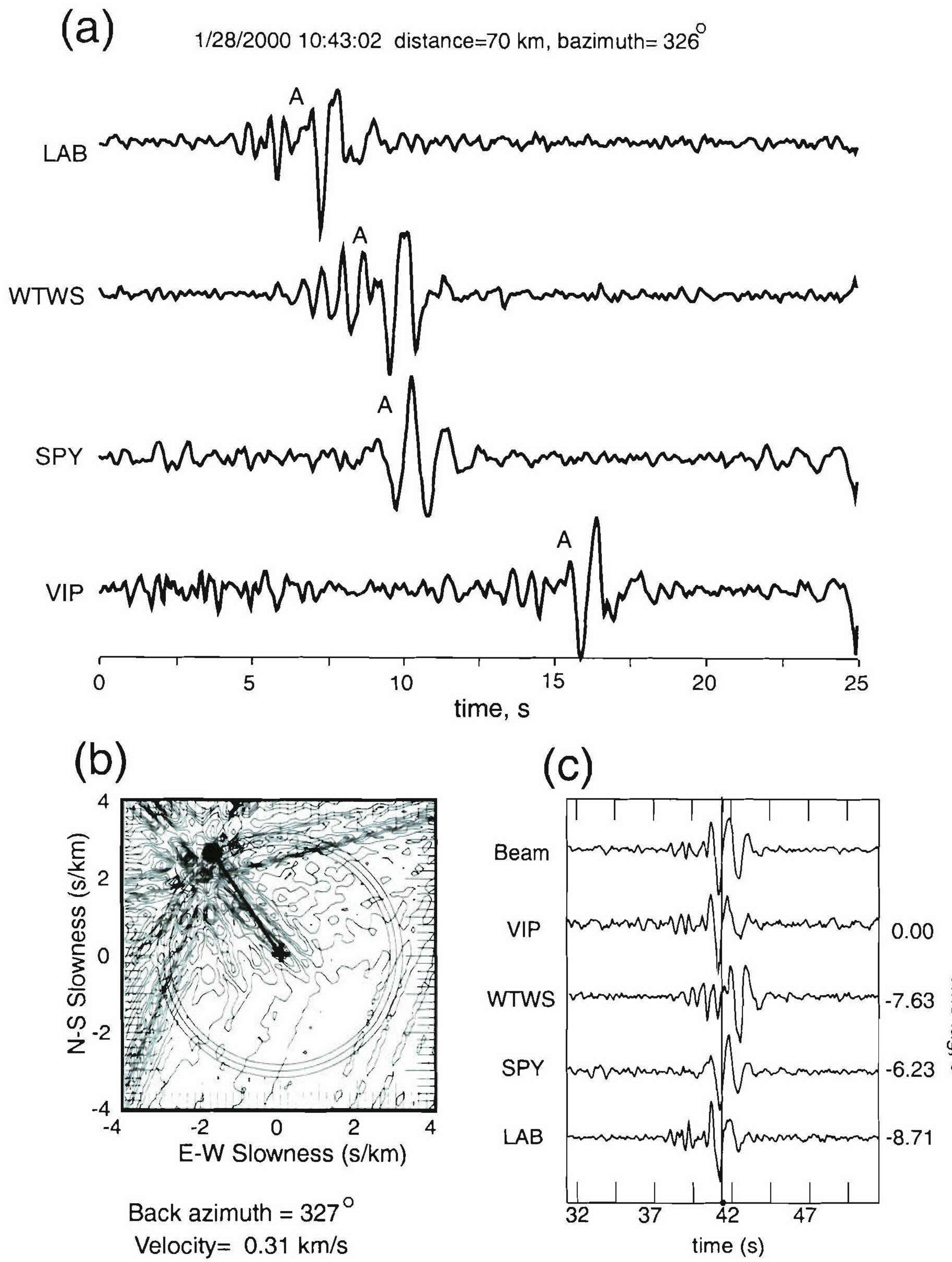

Figure 8: (a) Infrasound signals from a Kokchetav explosion recorded by Borovoye infrasound array. Signals are bandpass filtered between 0.8 and 5 Hz. (b) contour plot of beam power obtained by slant-stacking infrasound traces at different slownesses. Maximum beam power is obtained for phase velocity=0.31 km/s and back azimuth= 327°. (c) Expanded view of array beam trace (*top trace*) and corresponding infrasound traces aligned for the array beam.

2.5 Events from Other Regions

One mining event associated with an ice undermining is clearly detected both in seismic station and the infrasound array (Figure 9). The event is about 12.5 km SSW of the infrasound array site VIP. The $S - P$ time at BRVK station is 2.1 s. The infrasound travel time at VIP is about 36 s, giving an apparent group velocity of about 347 m/s. The array beam calculated for the event yields a phase velocity of 330 m/s, and azimuth of 217°(Figure 10). The infrasound arrivals at this short distance range indicate existence of a favorable tropospheric duct around the region.

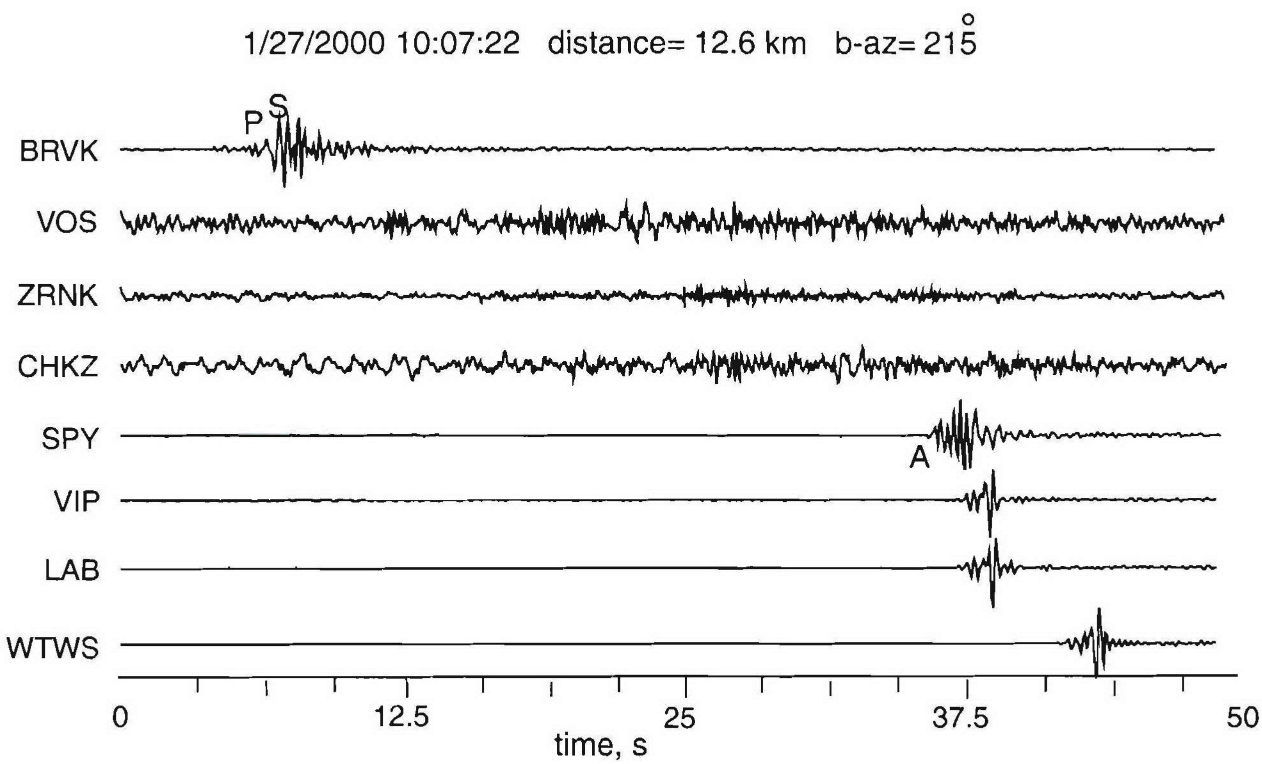

Figure 9: Seismic records (*top four traces*) and corresponding infrasound records (*bottom four traces*) from an explosion for ice undermining event near Borovoye array. The event is about 12 km SW of the array.

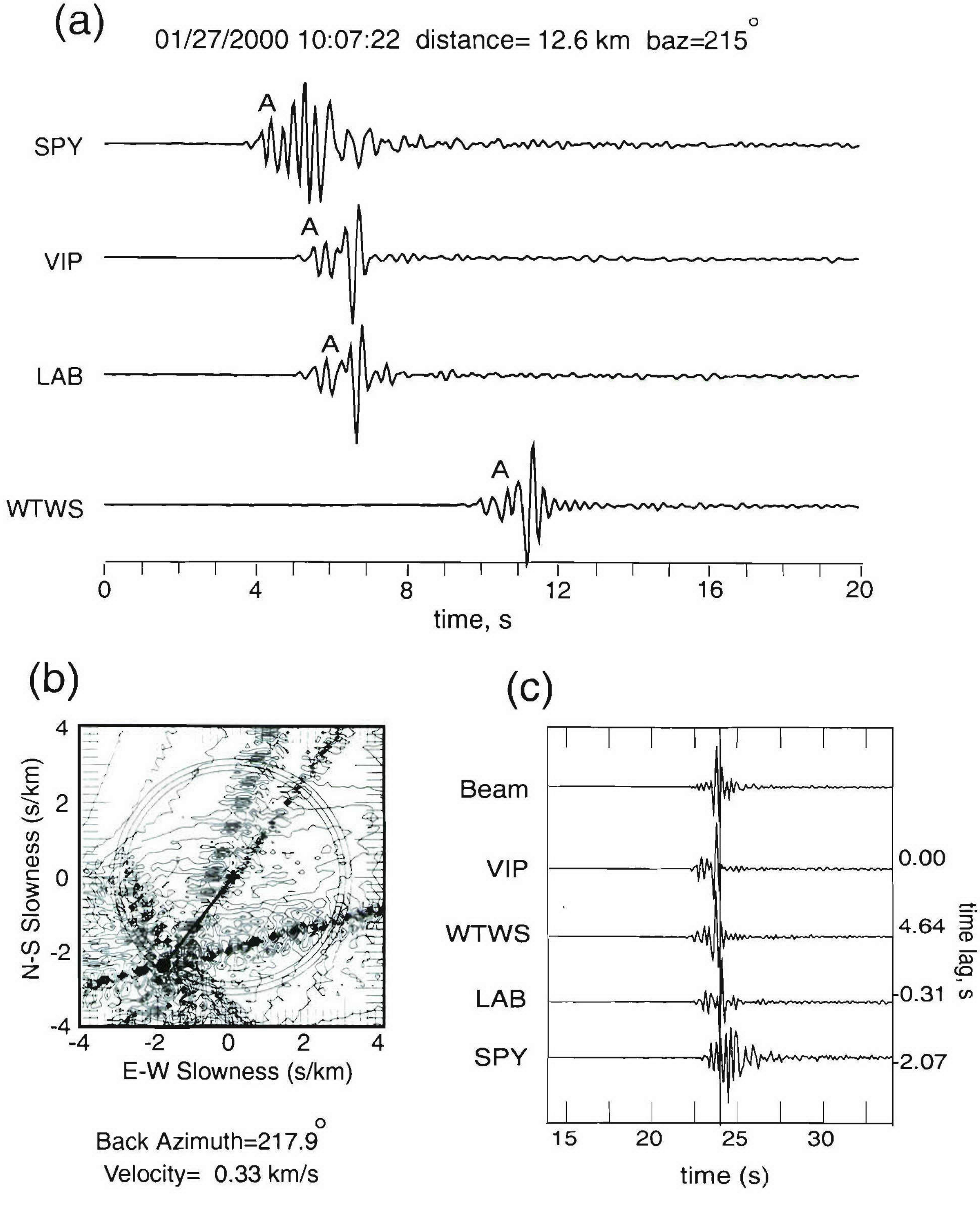

Figure 10: (a) Infrasound signals from an ice undermining recorded by Borovoye infrasound array. Signals are bandpass filtered between 0.8 and 5 Hz. (b) contour plot of beam power obtained by slant-stacking infrasound traces at different slownesses. Maximum beam power is obtained for phase velocity=0.33 km/s and back azimuth= 218°. (c) Expanded view of array beam trace (*top trace*) and corresponding infrasound traces aligned for the beam.

2.6 Modeling

In order to identify the infrasound arrivals, we ray traced through a suitable atmospheric model. The sound speed model is derived from mid-latitude (45°N) temperature profiles for January [Valley, 1965] and the well-known theoretical relation $c(T) = 20.1\sqrt{T(K)}$, where T is the temperature in degrees Kelvin. Above 130 km, average sound speeds from the 1962 U.S. Standard Atmosphere have been used. The wind profile is also included in the model via mid-latitude zonal wind model for winter from Georges and Beasley [1977] along with wind profiles measured by the high-resolution Doppler imager aboard the Upper Atmosphere Research Satellite (UARS) [Flemming et al., 1996].

Figure 11 compares the travel-time, phase velocity, and group velocity curves that result from exact method to ray trace through the winter temperature and wind model described above (Hagerty et al., 2002). Figure 11c shows that the first rays arriving at 220–250 km range have turned in the stratosphere (height $\sim$38 km). These stratospheric rays do not arrive at a distance range of about 380 km from the source (comparable to Borovoye–Ekibastuz path). This sound speed model predicts that the rays that arrive at Borovoye from the the source in Ekibastuz (Δ = 380 km) would be the ones turned in the thermosphere at heights higher than about 120 km. However, the predicted travel time (about 1300 s) and group velocity (about 300 m/s) for these thermospheric rays do not match the observed values at Borovoye array (travel time=1156s, and 320 m/s).

In order to produce infrasonic arrivals with the observed time and group velocity at Δ=380 km, a tropospheric duct must exist between Ekibastuz and Borovoye. This is supported by the observations of direct (tropospheric) infrasonic arrivals from Kokchetav explosions, located at about 70 km away from the Brovoye array and well within the shadow zone predicted by models with no tropospheric duct.

The existence of a tropospheric duct implies an increase in the effective sound speed between the surface and the tropopause (0–15 km)(see Hagerty et al., 2002). A modified sound-speed profile which contains a favorable tropospheric duct is presented in Hagerty et al. (2002) along with the resulting travel-time and velocity curves. The essense of the modified model is a fast troposphere and an elevated stratospheric lid. For this modified model, the first arrival at 380 km propagates through the stratosphere. The modified tropospheric profile results in good matches to the observed travel times and group velocity at Δ = 380 km, as well as the first arrival travel times at 70 km.

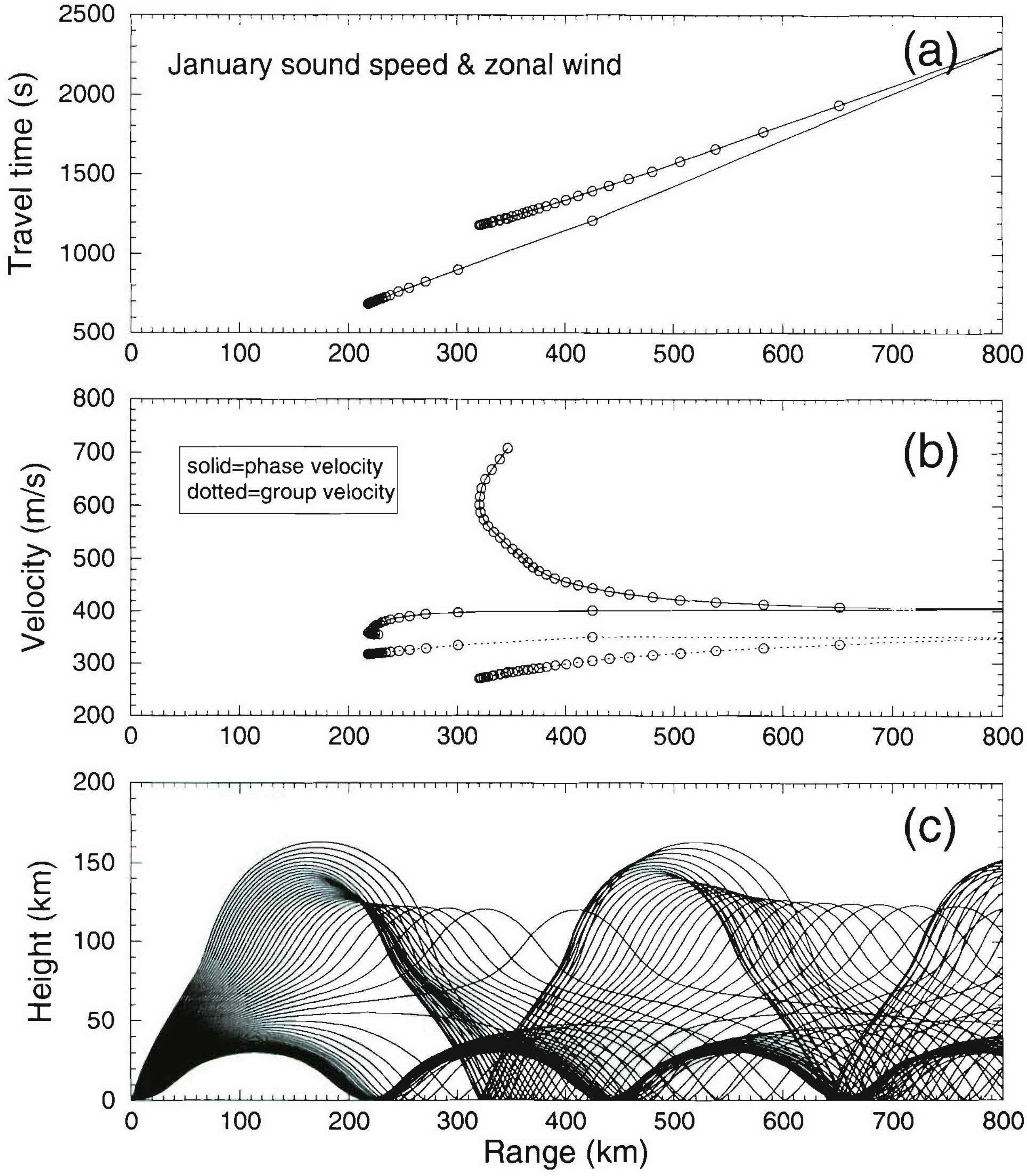

Figure 11: Results of ray tracing through a sound speed profile given by the 1962 U.S. Standard Atmosphere midlatitude temperature profile and the January zonal wind model. the exact wind treatment, a) Travel times. b) Phase (solid line) and group (dotted line) velocities. c) Ray paths computed for the exact method. The rays turn at a height where the effective speed equals the horizontal phase velocity at the surface.

2.7 Discussion and Conclusions

Infrasound signals generated by large mining explosions at Ekibastuz coal mines in Northern Kazakstan have been detected by a 4-element infrasound array deployed in Borovoye, Northern Kazakstan. During December, 1999 – February, 2000, we detected and located 161 seismic events from Ekibastuz region (Δ=380 km, BAZ= 113°). However, only 11 events of these seismic events were detected also on infrasound array. Hence, the infrasound detection is relatively low at Borovoye compared to that detected at Kurchatov array [Hagerty et al., 2002].

During the same period, we recorded 101 seismic events from Kuzbass mining region (Δ=1123 km, BAZ= 77°) in SW Siberia, Russia. Of these 101 seismic events, we acquired ground truth for 61 events. We were unable to detect positively any infrasound signals from Kuzbass region at Borovoye. Seasonally dependent zonal wind direction at mid-latitude might cause poor infrasound reception at certain paths [Hagerty et al., 2002]. It has also been argued that high surface winds near the receivers may also obstruct infrasound detection [Hagerty et al., 2002]. The directivity of blast and coupling of seismic and infrasound wavefields at source may also affect infrasound detection.

We have presented here an interpretation of the characteristics of infrasound propagation observed in Borovoye, northern Kazakstan. The infrasound signals associated with Ekibastuz mining blasts can be classified into two types. The first type consists of simple pulses with 2 to 3 s duration, while the second type consists of multiple pulses of similar amplitude arriving within about a 10–12 s window. For each event, similar infrasonic waveforms are observed at all four stations of the 4-element infrasound array with an aperture length of 2.5 km, suggesting that local receiver effects maybe negligible for shaping the waveforms.

Infrasound arrivals from both Ekibastuz (Δ=380 km) and Kokchetav (Δ=70 km) explosions support the existence of a tropospheric duct, produced by a temperature inversion and/or a westerly jet in the troposphere. In order to produce infrasonic arrivals with the observed time and group velocity at Δ=380 km, a tropospheric duct must exist between Ekibastuz and Borovoye. This is supported by the observations of direct (tropospheric) infrasonic arrivals from Kokchetav explosions, located at about 70 km away from the Brovoye array and well within the shadow zone predicted by models with no tropospheric duct.

The existence of a tropospheric duct implies an increase in the effective sound speed between the surface and the tropopause (0–15 km) [Hagerty et al., 2002]. A modified sound speed profile, which has a fast troposphere and an elevated stratospheric lid, produces the infrasonic arrivals at 380 km propagated through the stratosphere. The modified tropospheric profile results in good matches to the observed travel times and group velocity at Δ = 380 km, as well as the first arrival travel times at 70 km.

Although, large variability in the character of infrasound signals generated by Ekibastuz events over short time scales (hours to days) was argued as indicative of the rapidity of atmospheric fluctuations by Hagerty et al. (2002), two types of infrasonic signals observed at Brovoye may be due to the exciation at the source as well as directivity of explosion sources.

Section 3

Ground Truth Data of Large Mining Explosions in Altay-Sayan Region, Southwestern Siberia, Russia

3.1 Ground Truth Data.

The Kuzbass and Abakan are two coal mining regions in southwestern Siberia, Russia. They are very unusual in being the site of blasting activity that includes numerous explosions which can be detected teleseismically (Figure 12). In terms of size of seismic signals, these may be the largest routinely conducted blasting operations in Eurasia [Khalturin et al., 1997]. These extensive mining regions, which are close to the tectonically active Altay-Sayan, are also subject to frequent earthquakes. The Kuzbass mining area extends between 53 – 56°N and 86 – 88.5°E (Figure 12) and has a dozen coal mines as listed in Table 2. The Abakan mining region extends between 53.5 – 53.8°N and 91 – 91.5°E and there are at least three large mines (Table 2). The majority of these mines are open pits. Tashtagol and Sheregeshsky are the two underground mines located south of Kuzbass mining region (Figure 12).

On an average, these mines carry out 2–3 large blasts daily. Many of these blasts are strong enough to be detected by seismographic stations as far as 1,000 km. The average size of the blasts detected and located is around magnitude 3. We acquired ground truth information for 424 mining explosions (GT10 quality) carried out during 1999–2000 in the Kuzbass and Abakan regions. These blasts are listed in Table 3 and are plotted in Figure 12.

In August 1998, we installed a modern three-component, broadband seismograph at Yeltsovka (ELT) in collaboration with the Altay-Sayan Experimental and Methodical Seismological Expedition (ASEMSE), Siberian Branch of Russian Academy of Sciences in Novosibirsk, Russia. The station recorded continuously with a sampling rate of 100 samples/sec till the end of 1999. We acquired high-quality broadband seismic data with high frequency content (up to 50 Hz) at local distances from these mining blasts in Kuzbass–Sayan region.

For February, 1999 through June, 1999, we were able to associate 39 GT events given in Table 3 with the waveform data recorded at the station ELT. The average distance between ELT and Kuzbass mines is about 125 km, although the mines are distributed between 110 and 150 km of ELT station. The RMS error of these associated events at ELT is less than 1 s, indicating errors in ground truth data must be very small. The average $S - P$ time of Kuzbass events recorded at ELT varies between 15 and 22 s, while $S - P$ time at ELT is roughly about 40 to 45 s from Abakan region. For majority of events, the seismic signals are characterized by strong P-wave amplitudes, a typical characteristics of mining blasts. Vertical-component waveform data recorded at ELT from 10 blasts listed in Table 3 are shown in Figure 13.

Table 2: **List of mines in Kuzbass and Abakan regions**

Id	Name	Type
a	Kolmogorovsky-1	open pit coal mine
b	Kolmogorovsky-2	Karakanski, open pit coal mine
c	Kiselevsk	includes Bachatsky, Krasnobrodsky & Novosergeevsky open pit coal mine
d	Taldinsky	open pit coal mine
e	Badaevsky	open pit coal mine
f	Oldgerasky	open pit coal mine
g	Mezhdurechensk	includes Mezhdurechensky, Tomusinsky, Krasnogorsky & Sibirginsky open pit coal mines
h	Kaltansky	open pit coal mine
i	Listvyansky	open pit coal mine
j	Tashtagol	underground mines includes Sheregeshsky
k	Abakan-1	
l	Abakan-2	includes Chernogorsky and Izychsky open pit coal mines
m	Kedrovski	includes Chernigorosky open pit coal mines

Other mines in Kuzbass

	Mokhovsky	(53.5-53.6°N, 86.3-86.4°E) open pit coal mine
	Ossinikovsky	(53.12°N, 87.3-87.4°E), open pit coal mine

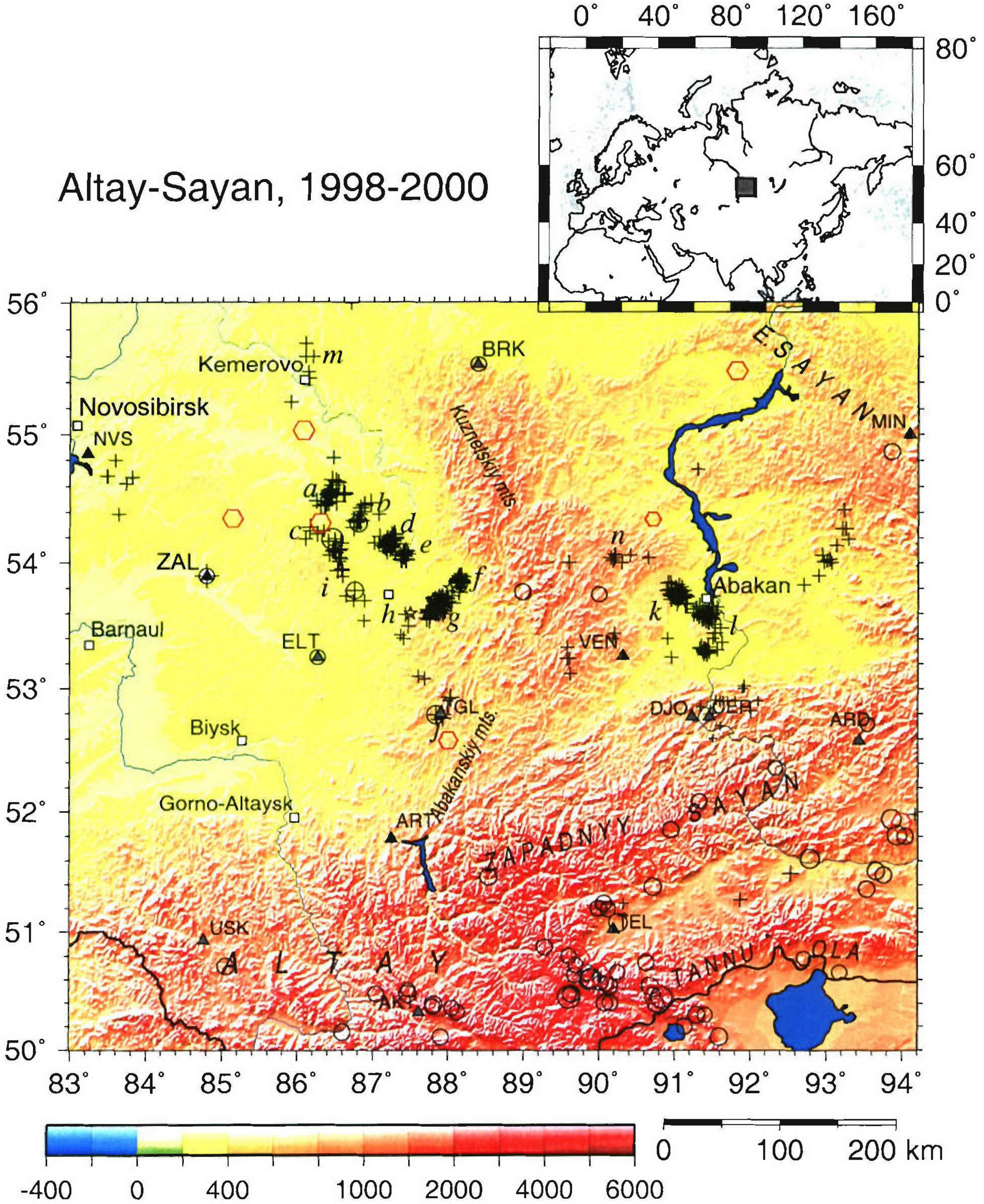

Figure 12: Locations of REB events (*red circles*) in Southwestern Siberia during 1995–1997 and PDE events (*black circle*). Mining blasts in 1998–2000 are plotted with *pluses*. Mining areas in Kuzbass and Abakan regions are indicated by cluster of events. IMS network station ZAL, LDEO/ASEMSE station ELT, and other local seismic stations in the region are plotted.

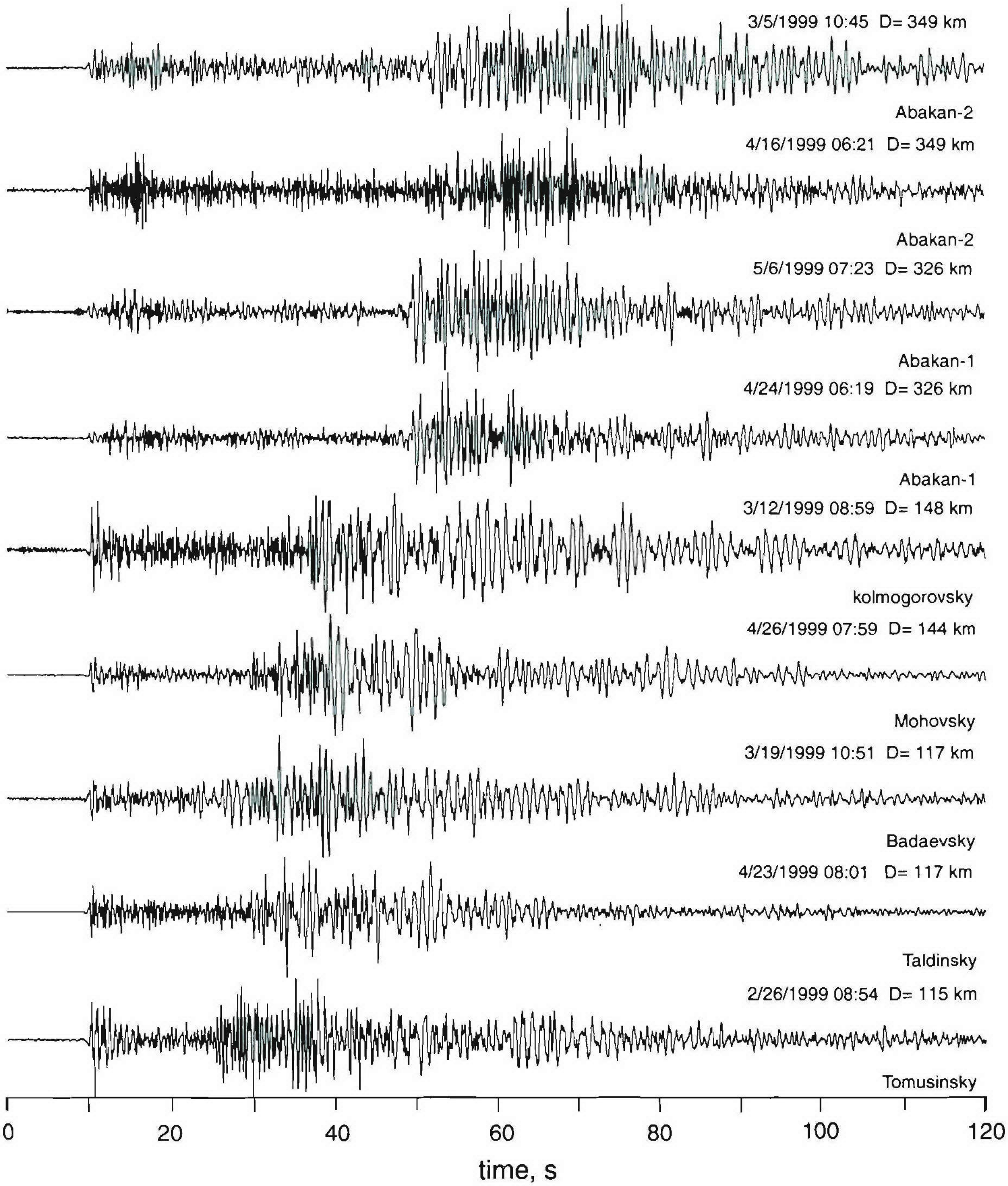

Figure 13: Selected waveform data of mining explosions from Kuzbass and Abakan regions recorded at ELT. Vertical-component traces are aligned to P wave arrivals. Origin time, epicentral distance, and name of the mines are given at the end of each trace.

3.2 Earthquakes in Altay-Sayan Region.

South of the Kuzbass and Abakan mining regions is a broad region of Altay-Sayan region which is tectonically active. For 1999, Altay-Sayan Experimental and Methodical Seismological Expedition (ASEMSE) located 134 earthquakes in the Altay-Sayan. The local magnitude of these events range from 2.4 to 4.9. Most of these earthquakes are recorded at the seismic station ELT. Example waveform data recorded at ELT from selected events during February – June, 1999 are shown in Figure 14. The waveforms associated with earthquakes are characterized by weak Pn and Pg, but stronger Lg arrivals.

We examined P/S spectral amplitude ratios for earthquakes and explosions in the region from a comparable set of earthquake and explosion data. Explosions with size less than 2.0 in body wave magnitude scale are eliminated in this analysis. Waveform data recorded at ELT, from a total of five explosions from Abakan region, 17 from Kuzbass region, and eight earthquakes from Altay-Sayan region, are analyzed to detemine Pg/Lg spectral ratio for finding seismic discriminant. The Lg windows are determined using a Gaussian weighting function, whose mean value is equivalent to a group velocity of 3.2 km/s and standard deviation, σ, equals to $\sigma_{ref} \times (\Delta/\Delta_{ref})$ [Kim et al., 1997]. Here, σ_{ref} (width of the Gaussian window) is 2.5 s at Δ_{ref} (reference distance) of 100 km, and Δ is the epicentral distance in kilometers. In this way, group velocity for Lg wave always lies between 3.48 and 2.96 km/s, while the window length varies with distance. Pg windows are determined by $Lg \times (1/\sqrt{3})$. A multitaper algorithm is used to calculate the spectral amplitude. The resulting spectral amplitudes are then resampled at 1 Hz between 5 and 15 Hz, and averaged spectral amplitude ratios are determined. Mean vertical component Pg/Lg spectral amplitude ratios in the frequency band of 5 to 15 Hz is 0.37 and 0.62 for earthquakes and explosions, respectively, suggesting that P/S spectral amplitude ratio would work well as a seismic discriminant in this region.

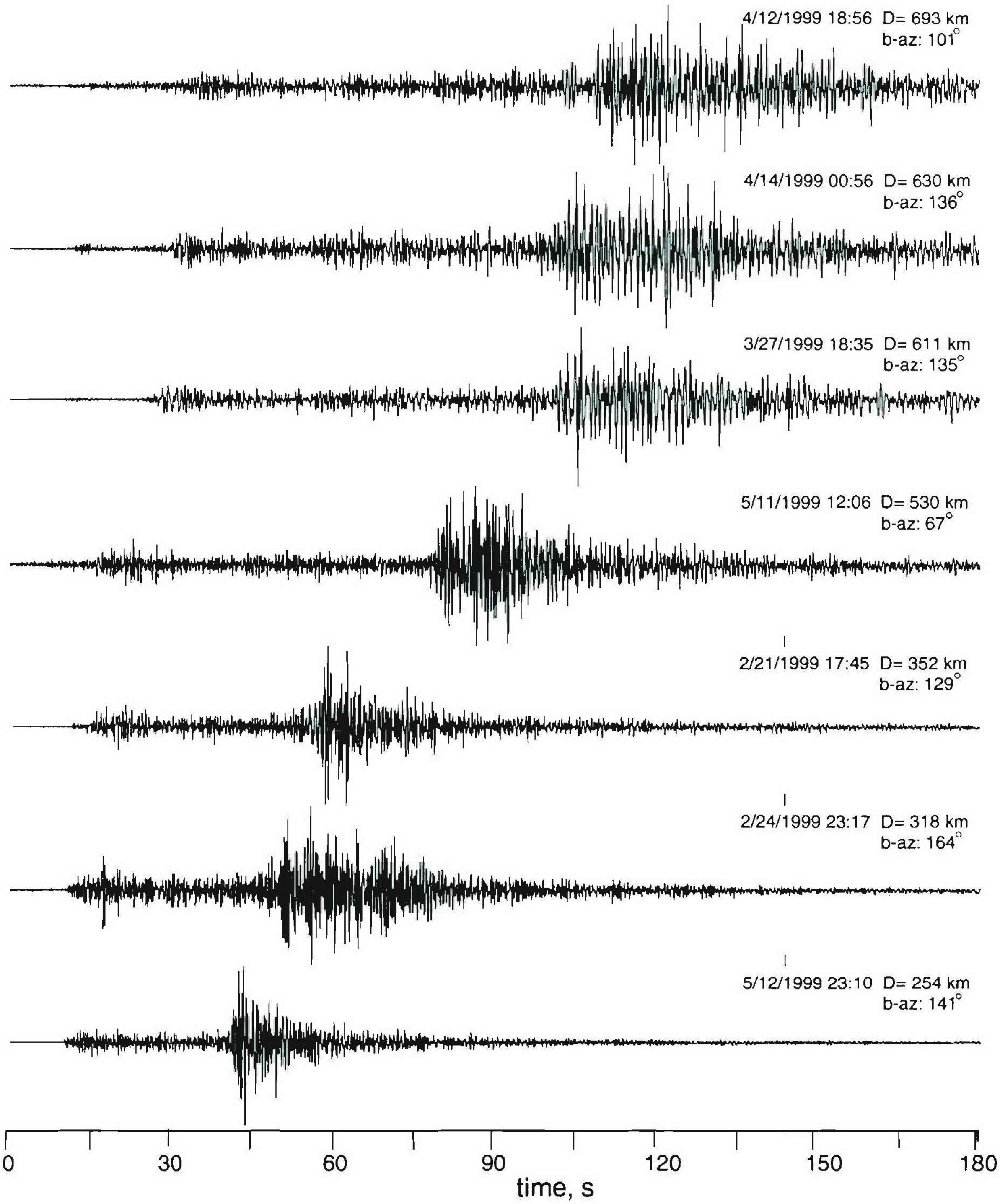

Figure 14: Vertical records at ELT from earthquakes in Altay-Sayan region. Traces are aligned at P-waves arrivals. Event magnitude varies from 2.4-3.7. P waves (Pn and Pg) arrivals are weak relative to Lg waves, a typical characteristic of earthquakes.

Table 3. Ground truth data of mining explosions in Kuzbass and Abakan regions

Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Energy (K)	Magnitude (m_b)	Yield (ton)	Location name
1999-01-05	08:45:54.6	53.58	91.42	9.1	3.5	-	Abakan-2
1999-01-06	07:56:50.5	54.11	87.16	8.8	3.4	154	Taldinsky
1999-01-14	06:01:30.0	53.87	88.15	9.4	3.6	-	Oldegrasky
1999-01-23	11:51:52.4	54.07	87.42	8.7	3.3	-	Badaevsky
1999-01-25	06:10:43.7	54.64	86.51	9.0	3.5	-	Kolmogorovsky-1
1999-01-26	09:14:16.1	53.61	87.92	9.5	3.7	-	Mezhdurechensk
1999-01-30	09:24:39.5	53.66	91.13	8.7	3.3	150.9	Abakan-1
1999-02-01	08:43:08.1	54.49	86.25	8.8	3.4	-	Kolmogorovsky-1
1999-02-01	10:39:43.9	54.21	87.09	8.7	3.3	-	Taldinsky
1999-02-04	08:06:49.6	53.62	87.76	8.6	3.3	90.0	Mezhdurechensky
1999-02-05	08:48:12.4	54.55	86.41	8.7	3.3	-	Kolmogorovsky
1999-02-05	09:38:50.8	53.73	91.15	8.7	3.3	182.3	Abakan-1
1999-02-10	06:52:23.0	54.22	87.24	8.9	3.4	135.0	Taldinsky
1999-02-12	09:27:15.5	53.73	91.07	9.2	3.5	-	Abakan-1
1999-02-24*	09:58:08.8	53.66	87.85	8.9	3.4	203.8	Krasnogorsky
1999-02-25*	07:07:23.1	54.18	87.22	8.7	3.3	-	Taldinsky
1999-02-26*	08:54:18.8	53.70	87.89	9.0	3.5	150.0	Tomusinsky
1999-03-03*	08:21:38.9	53.85	88.10	9.2	3.5	-	Oldgerasky
1999-03-05*	10:45:22.6	53.60	91.37	9.3	3.6	135.0	Abakan-2
1999-03-06*	06:38:39.1	54.32	86.78	8.8	3.4	239.4	Karakansky
1999-03-07*	10:57:14.8	54.45	86.88	9.0	3.5	-	Kolmogorovsky-2
1999-03-10*	09:48:52.0	53.71	87.86	9.4	3.6	-	Krasnogorsky
1999-03-12*	08:59:46.9	54.53	86.60	8.6	3.3	-	Kolmogorovsky-1
1999-03-19*	10:51:12.3	54.08	87.39	8.7	3.3	194.1	Bedaevsky
1999-03-24*	09:11:57.7	53.71	87.83	9.3	3.6	209.4	Sibirginsky
1999-03-26*	08:07:14.9	53.69	87.85	9.0	3.5	155.4	Sibirginsky
1999-03-30*	06:55:31.8	53.85	88.15	8.9	3.4	-	Oldgerasky
1999-03-31*	09:03:11.6	54.54	86.62	8.9	3.4	-	Kolmogorovsky-1
1999-04-02*	05:05:41.3	54.40	86.84	8.8	3.4	104.0	Kolmogorovsky-2
1999-04-02*	11:01:44.0	54.09	87.42	8.9	3.4	255.0	Badaevsky
1999-04-09*	09:36:25.1	54.05	87.42	8.9	3.4	294.9	Badaevsky
1999-04-12*	06:20:47.8	54.53	86.45	9.2	3.5	128.0	Mohosky
1999-04-16*	06:21:50.2	53.58	91.49	8.7	3.3	-	Abakan-2
1999-04-21	08:10:22.6	53.67	87.84	8.7	3.3	159.8	Krasnogorsky
1999-04-23	07:36:43.6	53.29	91.42	8.9	3.4	-	Abakan-2
1999-04-23*	08:01:05.0	54.14	87.23	9.7	3.8	168.7	Taldinsky
1999-04-24*	06:19:06.2	53.74	91.13	9.1	3.5	156.8	Abakan-1
1999-04-26*	07:59:59.4	54.55	86.45	8.8	3.4	113.0	Mohovsky
1999-04-30*	04:22:18.5	53.51	91.53	8.6	3.3	-	Abakan-2
1999-04-30*	05:34:19.8	54.05	87.40	8.9	3.4	-	Badaevsky
1999-05-06*	07:23:07.1	53.75	91.03	9.8	3.8	268.0	Chernogorsky
1999-05-08*	08:19:30.0	54.34	86.81	8.8	3.4	-	Kolmogorovsky-1
1999-05-14	06:42:35.5	53.55	91.41	9.4	3.6	-	Abakan-2
1999-05-21*	08:38:39.3	54.06	87.36	8.7	3.3	119.4	Badaevsky
1999-05-21*	10:48:08.9	54.18	87.18	9.1	3.5	-	Taldinsky
1999-05-22*	09:57:31.4	53.60	87.70	8.7	3.3	217.0	Mezhdurechensky

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Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Energ (K)	Magnitude (m_b)	Yield (ton)	Location name
1999-05-27*	08:26:21.6	54.48	86.51	9.2	3.5	440.9	Kolmogorovsky
1999-05-28*	09:14:29.4	54.03	87.37	9.2	3.5	-	Badaevsky
1999-05-28*	09:52:20.7	54.20	87.29	9.3	3.6	-	Taldinsky
1999-06-03*	09:02:24.9	53.30	91.40	8.7	3.3	126.8	Abakan-2
1999-06-09*	08:48:44.8	53.68	91.03	9.3	3.6	230.0	Chernogorsky
1999-06-14*	06:49:05.9	53.86	88.09	8.8	3.4	117.6	Oldgerasky
1999-06-18*	06:39:51.0	54.53	86.40	9.0	3.5	257.9	Kolmogorovsky-1
1999-06-23*	07:50:59.3	54.15	87.21	9.1	3.5	169.0	Taladinsky
1999-06-29*	09:34:03.5	53.74	91.08	9.1	3.5	-	Abakan-1
1999-06-30*	08:27:54.2	54.19	87.28	9.3	3.6	208.0	Taladinsky
1999-07-01	09:09:03.7	54.48	86.37	9.1	3.5	130.9	Kolmogorovsky-1
1999-07-02	06:11:07.0	53.30	91.40	8.7	3.3	202.0	Abakan-2
1999-07-07	07:37:10.8	53.65	87.78	8.9	3.4	164.7	Sibirginsky
1999-07-07	08:54:02.9	53.65	87.82	8.7	3.3	472.9	Mezhdurechinsky
1999-07-10	09:51:31.8	53.73	91.03	9.4	3.6	297.0	Chernogorsky
1999-07-14	06:53:17.1	53.59	91.43	9.0	3.5	156.4	Abakan-2
1999-07-14	07:29:27.0	53.66	87.84	9.5	3.7	429.8	Sibirginsky
1999-07-23	08:04:13.6	53.72	87.82	8.8	3.4	209.4	Sibirginsky
1999-07-22	10:55:13.0	54.08	87.41	9.3	3.6	-	Badaevsky
1999-07-28	07:20:02.9	54.18	87.24	8.9	3.4	186.2	Taldinsky
1999-07-30	06:51:42.7	54.45	86.35	9.0	3.5	125.0	Bachatsky
1999-08-07	09:00:46.5	53.63	91.28	8.6	3.3	-	Abakan-1
1999-08-10	06:02:43.0	53.75	91.08	8.6	3.3	-	Abakan-1
1999-08-11	08:06:33.3	53.62	87.85	9.5	3.7	544.7	Sibirginsky
1999-08-17	08:21:13.7	54.15	87.18	9.3	3.6	262.0	Taldinsky
1999-08-18	07:32:48.6	53.71	87.79	8.8	3.4	185.1	Krasnogorsky
1999-08-18	08:46:48.0	53.73	91.01	9.0	3.5	138.0	Chernogorsky
1999-08-19	08:57:37.5	53.56	91.38	8.9	3.4	-	Abakan-2
1999-08-19	09:04:18.3	54.08	87.41	9.0	3.5	-	Badaevsky
1999-08-20	08:20:34.6	53.74	87.88	8.6	3.3	111.9	Krasnogorsky
1999-08-23	09:29:43.6	54.17	87.25	8.9	3.4	144.5	Taldinsky
1999-09-01	07:31:14.3	53.69	87.88	8.2	3.1	173.4	Krasnogorsky
1999-09-01	09:25:10.8	54.10	87.43	9.1	3.5	-	Badaevsky
1999-09-02	08:20:42.9	53.62	91.51	9.7	3.8	-	Abakan-2
1999-09-03	08:37:16.6	53.77	91.02	9.9	3.9	378	Chernogorsky
1999-09-09	06:23:28.5	53.61	87.70	8.6	3.3	120.4	Mezhdurechensky
1999-09-10	07:16:14.5	53.64	87.79	9.0	3.5	278.3	Mezhdurechensky
1999-09-10	07:21:00.1	53.62	87.80	8.8	3.4	241.3	Krasnogorsky
1999-09-18	07:32:59.3	54.15	87.19	9.5	3.7	129.5	Taldinsky
1999-09-21	09:48:11.2	54.03	87.43	8.8	3.4	132.4	Badaevsky
1999-09-21	12:14:36.8	54.11	86.51	8.8	3.4	-	Kiselevsky
1999-10-06	08:01:35.0	54.33	86.80	8.9	3.4	105.3	Kolmogorovsky-2
1999-10-07	08:59:09.2	54.06	87.39	9.1	3.5	-	Badaevsky
1999-10-09	07:48:33.8	53.84	88.16	9.3	3.6	175.1	Oldgerasky
1999-10-14	11:53:05.1	54.16	87.20	9.0	3.5	-	Taldinsky
1999-10-15	06:46:59.5	53.62	87.74	8.8	3.4	241.3	Mezhdurechensky
1999-10-15	07:29:12.2	53.77	91.07	9.1	3.5	113.4	Abakan-1
1999-10-15	09:30:55.8	54.09	87.42	9.0	3.5	-	Badaevsky

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Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Energ (K)	Magnitude (m_b)	Yield (ton)	Location name
1999-10-18	08:57:31.3	53.67	87.81	9.4	3.6	230.8	Krasnogorsky
1999-10-19	06:49:08.6	53.74	87.92	8.6	3.3	335.0	Tomusinsky
1999-10-22	08:27:47.6	54.34	86.79	9.3	3.6	170.0	Mokhovsky
1999-10-24	04:00:10.5	52.79	87.89	9.7	3.8	128.5	Tashtagol
1999-10-24	04:00:34.2	52.79	87.84	10.1	4.0	-	Tashtagol
1999-10-26	09:16:09.8	54.16	87.16	9.0	3.5	141.0	Taldinsky
1999-10-29	05:11:58.3	53.29	91.40	8.7	3.3	-	Abakan-2
1999-10-29	05:26:01.9	53.69	87.93	8.8	3.4	284.3	Krasnogorsky
1999-10-29	10:31:34.5	54.15	87.22	9.1	3.5	162.4	Taldinsky
1999-11-05	05:38:22.0	53.44	91.53	9.0	3.5	121.7	Abakan-2
1999-11-05	08:20:25.0	53.73	91.05	9.0	3.5	160.0	Abakan-1
1999-11-12	08:00:31.6	53.77	91.07	8.6	3.3	104.3	Abakan-1
1999-11-15	08:59:50.5	53.80	88.02	8.9	3.4	256.9	Sibirginsky
1999-11-18	06:54:55.7	54.40	86.85	8.9	3.4	130.6	Kolmogorovsky-2
1999-11-23	09:47:19.7	53.70	87.90	8.2	3.1	402.8	Mezhdurechensky
1999-11-24	09:58:29.6	53.67	87.98	8.5	3.2	202.8	Krasnogorsky
1999-11-24	10:33:46.8	54.54	86.61	8.6	3.3	-	Kolmogorovsky-1
1999-11-25	09:25:53.2	53.73	91.00	9.8	3.8	150.0	Abakan-1
1999-11-27	06:20:34.6	54.15	87.22	8.6	3.3	-	Taldinsky
1999-11-29	09:40:10.1	53.67	87.85	9.7	3.8	458.1	Sibirginsky
1999-11-30	09:56:37.0	54.13	87.22	9.5	3.7	-	Taldinsky
1999-11-30	10:15:54.4	53.65	91.49	8.8	3.4	-	Abakan-2
1999-12-07	09:01:20.3	53.64	87.86	8.9	3.4	234.9	Krasnogorsky
1999-12-10	08:33:09.0	53.70	87.79	9.1	3.5	108.7	Sibirginsky
1999-12-14	08:52:48.4	54.19	87.22	8.8	3.4	150.0	Taldinsky
1999-12-17	09:01:09.9	53.60	87.49	8.6	3.3	160.7	Krasnogorsky
1999-12-17	09:17:19.8	53.68	87.85	9.2	3.5	299.5	Mezhdurechensky
1999-12-18	08:37:15.2	54.17	87.26	9.0	3.5	-	Taldinsky
1999-12-23	08:51:14.5	53.62	87.84	8.9	3.4	129.0	Mezhdurechensky
1999-12-25	12:34:54.9	54.09	87.45	8.7	3.3	-	Badaevsky
1999-12-28	08:23:08.0	54.20	87.25	9.7	3.8	209.1	Taldinsky
1999-12-30	05:59:56.5	53.61	87.75	9.0	3.5	319.4	Krasnogorsky
1999-12-30	07:05:02.2	53.90	88.16	8.9	3.4	117.2	Oldgerasky
1999-12-30	07:46:23.2	54.56	86.44	9.2	3.5	101.0	Karakansky
1999-12-30	08:37:11.5	53.78	90.96	8.6	3.3	-	Abakan-1
2000-01-11	08:52:05.5	53.67	87.85	8.8	3.4	110	Sibirginsky
2000-01-12	06:35:54.0	53.70	88.00	8.6	3.3	166.5	Mezhdurechinsky
2000-01-12	07:46:18.2	54.06	86.34	8.7	3.3	110.9	Krasniy Brod
2000-01-12	08:17:53.3	53.80	88.12	8.8	3.4	164	Tomusinsky
2000-01-12	09:19:28.5	53.72	87.91	8.3	3.1	169.8	Krasnogorsky
2000-01-14	06:16:11.0	53.90	88.10	8.2	3.1	172.0	Mezhdurechinsky
2000-01-14	08:31:03.8	53.77	91.06	9.3	3.6	-	Abakan-1
2000-01-17	08:34:55.8	53.57	87.65	8.7	3.3	210.2	Karakansky
2000-01-17	08:46:19.1	53.70	87.91	8.7	3.3	-	Mezhdurechinsky
2000-01-17	08:49:04.0	53.76	87.23	7.5	2.8	-	Osinnikovsky
2000-01-17	09:39:58.9	53.86	88.11	9.0	3.5	210	Krasnogorsky
2000-01-17	10:39:11.0	54.20	86.00	7.2	2.6	-	Bachatsky
2000-01-18	08:40:08.0	54.10	86.10	8.2	3.1	-	Taldinsky

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Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Energ (K)	Magnitude (m_b)	Yield (ton)	Location name
2000-01-18	09:33:23.1	54.24	87.16	8.1	3.0	-	Taldinsky
2000-01-18	09:53:44.3	53.66	87.85	8.7	3.3	122.3	Sibirginsky
2000-01-18	09:54:43.7	53.70	87.84	8.7	3.3	-	Tomusinsky
2000-01-20	08:29:53.1	54.03	86.46	8.1	3.0	418.6	Bachatsky
2000-01-20	08:31:43.0	54.10	86.40	8.7	3.3	-	Taldinsky
2000-01-20	08:46:45.9	53.61	87.73	8.8	3.4	418	Mezhdurechinsky
2000-01-20	08:46:47.1	53.60	87.69	9.0	3.5	107	Sibirginsky
2000-01-20	10:05:44.6	53.62	87.89	8.5	3.2	186.6	Krasnogorsky
2000-01-21	07:29:08.7	53.61	87.72	8.2	3.1	110.8	Mezhdurechinsky
2000-01-21	09:34:33.9	53.71	90.95	9.1	3.5	-	Abakan-1
2000-01-22	08:09:49.8	54.07	87.39	8.7	3.3	-	Erunakovsky
2000-01-24	08:15:00.9	54.02	86.38	8.0	3.0	-	Bachatsky
2000-01-24	09:06:46.5	53.73	88.33	7.9	2.9	-	Olzherassky
2000-01-24	09:48:47.0	53.80	87.90	8.7	3.3	162.6	Mezhdurechinsky
2000-01-24	11:00:16.7	54.25	86.97	8.5	3.2	-	Karakansky
2000-01-26	04:40:45.8	54.22	86.07	8.4	3.2	-	Krasniy Brod
2000-01-26	08:39:43.2	53.97	86.57	8.0	3.0	-	Krasniy Brod
2000-01-26	08:42:19.6	53.71	87.78	9.2	3.5	117	Mezhdurechinsky
2000-01-26	08:55:40.3	54.20	86.53	8.3	3.1	140	Kedrovsky
2000-01-26	09:56:02.5	54.22	86.12	8.5	3.2	-	Bachatsky
2000-01-26	10:36:33.4	53.67	87.91	8.7	3.3	-	Krasnogorsky
2000-01-26	11:16:54.5	54.15	87.20	9.0	3.5	-	Taldinsky
2000-01-26	14:42:30.1	51.49	92.54	9.2	3.5	-	Abakan-2
2000-01-28	09:17:37.3	53.68	87.76	8.2	3.1	117	Mezhdurechinsky
2000-01-28	10:31:27.0	53.60	87.70	8.3	3.1	115.8	Sibirginsky
2000-01-28	11:06:32.3	53.75	91.05	9.1	3.5	-	Abakan-1
2000-01-31	08:25:45.5	53.99	86.29	7.2	2.6	-	Krasniy Brod
2000-01-31	10:31:33.7	54.23	87.13	8.6	3.3	107.4	Mezhdurechinsky
2000-02-01	07:05:35.7	53.51	87.28	8.5	3.2	197	Tomusinsky
2000-02-01	08:33:06.1	53.52	86.75	7.8	2.9	-	-
2000-02-01	09:13:17.2	53.65	87.72	9.0	3.5	-	Sibirginsky
2000-02-01	09:25:35.0	53.71	87.97	7.9	2.9	-	Kazsky
2000-02-02	07:35:28.1	53.98	86.22	8.2	3.1	117	Sibirginsky
2000-02-02	11:00:21.8	54.30	86.98	8.6	3.3	-	Karaknsky
2000-02-03	06:09:30.3	54.16	87.06	8.8	3.4	-	Taldinsky
2000-02-03	07:39:16.5	54.10	86.21	8.1	3.0	-	Krasniy Brod
2000-02-03	08:32:13.0	54.29	86.49	8.4	3.2	-	Karakansky
2000-02-04	08:58:34.6	53.66	87.83	8.3	3.1	192	Mezhdurechinsky
2000-02-04	09:19:05.2	53.89	88.01	8.8	3.4	103.7	Sibirginsky
2000-02-04	09:46:20.6	53.73	87.82	8.3	3.1	219	Olzherassky
2000-02-09	08:26:13.3	53.73	91.06	9.2	3.5	-	Abakan-1
2000-02-09	09:15:53.3	54.20	86.24	7.5	2.8	-	Bachatsky
2000-02-10	08:41:11.7	53.59	87.71	8.2	3.1	126	Krasnogorsky
2000-02-10	10:03:31.7	54.13	86.02	8.2	3.1	-	Bachatsky
2000-02-11	08:21:51.9	53.95	86.84	7.9	2.9	-	Taldinsky
2000-02-11	08:46:23.1	53.84	88.18	9.2	3.5	192	Mezhdurechinsky
2000-02-11	09:14:16.1	53.63	87.76	8.5	3.2	103.7	Sibirginsky
2000-02-11	10:23:08.1	54.06	87.41	8.7	3.3	-	Erunakovsky

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Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Energ (K)	Magnitude (m_b)	Yield (ton)	Location name
2000-02-16	08:31:52.1	54.43	86.65	8.7	3.3	-	Karakansky
2000-02-16	08:36:42.4	53.62	87.84	8.3	3.1	221	Mezhdurechinsky
2000-02-16	09:25:19.0	53.90	87.70	8.5	3.2	-	Erunakovsky
2000-02-16	09:32:28.8	54.53	86.05	8.6	3.3	-	Bachatsky
2000-02-16	10:55:15.2	54.26	85.96	8.5	3.2	-	Bachatsky
2000-02-18	07:46:39.6	54.02	86.55	8.3	3.1	-	Krasniy Brod
2000-02-18	09:46:08.0	54.20	86.60	8.5	3.2	-	Krasniy Brod
2000-02-18	10:54:11.1	54.23	87.12	8.0	3.0	-	Taldinksy
2000-02-21	09:00:47.9	53.95	85.92	8.3	3.1	-	Bachatsky
2000-02-18	07:46:39.6	54.02	86.55	8.3	3.1	-	Krasniy Brod
2000-02-21	09:02:45.2	54.05	86.33	8.1	3.0	-	Krasniy Brod
2000-02-21	11:58:55.1	53.67	86.69	7.7	2.9	-	-
2000-02-22	08:37:24.1	54.13	86.93	8.9	3.4	-	Taldinsky
2000-02-22	08:52:31.8	53.70	87.89	8.6	3.3	343	Mezhdurechensky
2000-02-22	09:07:32.8	53.63	87.82	8.7	3.3	164.5	Sibirginsky
2000-02-23	03:26:07.1	53.51	87.37	8.6	3.3	184	Tomusinsky
2000-02-23	09:47:39.6	54.26	85.83	8.3	3.1	-	Bachatsky
2000-02-23	11:34:49.0	54.05	87.39	8.8	3.4	-	Erunakovsky
2000-02-24	08:20:32.8	53.62	87.63	7.9	2.9	-	Sibirginsky
2000-02-24	08:24:50.9	53.97	86.29	7.5	2.8	-	Krasniy Brod
2000-02-24	09:47:32.3	53.77	88.01	7.6	2.8	128	Krasnogorsky
2000-02-24	10:02:23.8	54.42	86.64	8.4	3.2	-	Karansky
2000-02-26	04:27:33.3	53.51	87.45	8.3	3.1	-	Mezhdurechinsky
2000-02-26	12:39:27.7	54.09	87.40	8.8	3.4	-	Erunakovsky
2000-03-01	08:24:58.9	54.47	86.41	8.8	3.4	-	Karansky
2000-03-01	12:36:03.1	54.15	87.20	8.8	3.4	-	Taldinsky
2000-03-02	09:11:00.1	53.77	91.01	9.0	3.5	-	Abakan-11
2000-03-03	08:02:58.6	53.59	87.92	8.3	3.1	275.7	Kazsky
2000-03-03	08:13:56.6	53.80	88.12	8.6	3.3	-	Olzherassky1
2000-03-03	08:21:48.6	54.38	85.90	8.5	3.2	220.0	Bachatsky
2000-03-03	08:25:51.3	53.61	87.77	8.6	3.3	275.6	Sibirginsky
2000-03-07	09:35:03.3	54.02	87.38	8.9	3.4	-	Erunakovsky
2000-03-11	09:07:54.7	54.09	87.42	8.6	3.3	-	Erunakovsky
2000-03-12	07:10:39.3	54.46	86.89	8.6	3.3	-	Karakansky
2000-03-13	09:24:53.6	54.12	87.16	8.6	3.3	-	Taldinsky
2000-03-14	09:31:12.9	54.00	86.23	8.5	3.2	-	Krasniy Brod
2000-03-14	09:48:10.2	53.64	87.63	8.2	3.1	341.2	Sibirginsky
2000-03-15	06:20:20.3	54.06	86.23	8.5	3.2	-	Krasniy Brod
2000-03-15	09:49:02.2	53.73	85.52	7.3	2.7	188.8	-
2000-03-15	10:45:26.4	53.72	87.78	8.4	3.2	-	Sibirgisky
2000-03-16	06:00:15.0	54.10	86.80	8.3	3.1	-	Taldinsky
2000-03-16	08:25:03.0	53.54	87.40	7.9	2.9	230.7	Kaltansky
2000-03-16	09:58:44.4	53.67	87.86	8.5	3.2	110.9	Mezhdurechensky
2000-03-16	10:49:42.6	55.30	86.73	7.8	2.9	-	Kedrovsky
2000-03-16	10:57:16.0	53.00	86.30	6.3	2.2	-	-
2000-03-17	08:51:36.1	53.78	91.09	10.1	4.0	-	Abakan-1
2000-03-17	09:11:48.2	53.67	87.82	8.7	3.3	-	Kazsky
2000-03-17	10:11:2.4	54.12	86.33	8.4	3.2	-	Krasniy

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Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Energ (K)	Magnitude (m_b)	Yield (ton)	Location name
2000-03-18	07:37:28.8	53.77	88.14	9.4	3.6	143.8	Olzherassky
2000-03-18	10:37:35.1	54.38	86.82	8.6	3.3	-	Karakansky
2000-03-19	08:09:50.9	54.15	86.25	8.4	3.2	-	Krasniy Brod
2000-03-19	10:09:03.9	53.75	86.77	7.9	2.9	-	-
2000-03-20	06:51:17.0	54.57	86.42	9.2	3.5	202.0	Karakansky
2000-03-20	09:34:45.6	54.10	86.30	8.0	3.0	-	Krasniy Brod
2000-03-21	08:47:44.0	52.40	87.80	6.3	2.2	233.9	-
2000-03-21	09:25:41.2	53.67	87.83	8.5	3.2	-	Kazsky
2000-03-21	09:33:19.5	54.17	87.05	8.8	3.4	-	Taldinsky
2000-03-21	09:36:23.1	53.52	87.27	8.0	3.0	-	Kaltansky
2000-03-24	07:23:20.8	53.57	87.67	8.3	3.1	127.5	Sibirginsky
2000-03-24	09:23:48.0	52.70	87.10	7.6	2.8	252.2	-
2000-03-29	07:17:06.7	53.96	86.60	7.4	2.7	-	Krasniy Brod
2000-03-29	07:36:28.2	53.65	87.80	8.2	3.1	123.4	Sibirginsky
2000-03-29	08:12:29.4	54.28	86.48	8.3	3.1	225.6	Krasniy Brod
2000-03-31	03:55:24.0	53.52	87.41	8.0	3.0	-	Kaltansky
2000-03-31	06:57:50.1	54.10	86.50	7.3	2.7	-	Krasniy Brod
2000-03-31	07:46:30.5	53.96	86.48	7.2	2.6	169.9	Krasiy Brod
2000-03-31	08:30:28.9	54.09	87.41	9.1	3.5	-	Erunakovsky
2000-03-31	08:54:14.0	54.20	86.02	8.4	3.2	-	Bachatsky
2000-04-02	07:00:33.1	53.88	88.10	8.9	3.4	-	Olzherassky
2000-04-02	07:13:38.4	54.22	86.41	8.5	3.2	-	Krasniy Brod
2000-04-02	07:16:25.9	53.68	87.89	8.4	3.2	-	Krasniy Brod
2000-04-04	06:37:21.3	54.51	86.40	9.0	3.5	106.4	Karakansky
2000-04-06	05:42:35.9	53.30	87.26	7.8	2.9	113.0	Osinnikovsky
2000-04-06	07:49:29.4	53.84	88.24	8.4	3.2	186.2	Olzherassky
2000-04-06	09:31:01.2	54.32	86.20	7.4	2.7	-	Bachatsky
2000-04-07	07:21:44.8	54.12	86.30	8.4	3.2	113.8	Krasniy
2000-04-07	07:53:40.4	53.74	91.04	9.9	3.9	-	Abakan-1
2000-04-07	08:16:56.2	54.12	87.36	8.1	3.0	-	Erunakovsky
2000-04-07	08:35:34.1	53.67	87.91	8.3	3.1	-	Krasnogorsky
2000-04-07	09:28:11.3	53.74	86.91	7.0	2.5	-	-
2000-04-07	11:00:15.9	54.10	86.04	8.7	3.3	-	Bachatsky
2000-04-08	08:55:55.5	54.15	87.21	9.0	3.5	-	Taldinsky
2000-04-12	07:07:21.9	54.23	87.26	7.9	2.9	138.3	Taldinsky
2000-04-12	07:20:25.2	53.97	86.07	7.9	2.9	-	Bachatsky
2000-04-12	07:25:46.9	53.62	87.72	8.5	3.2	-	Sibirginsky
2000-04-12	08:13:54.2	54.11	86.23	8.2	3.1	-	Krasniy Brod
2000-04-13	08:06:53.4	54.24	87.16	7.8	2.9	231.1	Taldinsky
2000-04-13	08:17:00.5	53.69	87.88	7.8	2.9	-	Mezhdurechensky
2000-04-13	08:26:33.5	54.12	86.39	8.5	3.2	-	Krasniy
2000-04-13	08:59:51.9	53.75	86.81	8.0	3.0	-	-
2000-04-14	06:14:57.0	53.84	88.16	8.8	3.4	114.1	Olzherassky
2000-04-17	07:27:05.7	53.97	86.27	7.0	2.5	286.7	Krasniy Brod
2000-04-17	08:30:12.8	53.78	88.35	8.4	3.2	-	Olzherassky
2000-04-17	09:47:11.7	53.55	87.35	7.2	2.6	109.0	Kaltansky
2000-04-18	06:18:17.5	54.14	86.29	8.9	3.4	-	Krasniy
2000-04-18	07:29:38.5	54.03	86.49	-	-	-	Krasniy Brod

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Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Energ (K)	Magnitude (m_b)	Yield (ton)	Location name
2000-04-19	07:19:36.3	53.56	87.71	8.0	3.0	174.9	Sibirginsky
2000-04-19	09:33:47.1	54.26	87.31	8.0	3.0	-	Taldinsky
2000-04-20	06:08:08.4	54.13	87.17	8.8	3.4	-	Taldinsky
2000-04-20	09:16:59.9	54.55	86.43	9.3	3.6	232.8	Karakansky
2000-04-21	07:14:39.4	53.55	91.49	9.1	3.5	-	Abakan-2
2000-04-24	08:20:58.2	52.32	87.17	6.8	2.4	-	-
2000-04-24	08:27:46.6	53.98	86.42	8.1	3.0	-	Krasniy Brod
2000-04-25	08:29:47.6	53.66	87.84	8.2	3.1	379.6	Sibirginsky
2000-04-26	07:33:50.4	53.61	87.72	8.2	3.1	-	Sibirginsky
2000-04-26	09:26:22.1	54.13	86.05	7.8	2.9	-	Bachatsky
2000-04-27	07:22:17.3	53.98	86.33	8.1	3.0	116.7	Krasniy Brod
2000-04-27	07:34:58.0	54.61	86.05	8.1	3.0	-	-
2000-04-27	08:42:31.3	54.18	86.35	7.6	2.8	-	Krasniy
2000-04-27	09:00:10.5	53.70	91.03	8.7	3.3	-	Abakan-1
2000-04-28	06:17:28.3	53.83	88.12	8.8	3.4	-	Olzherassky
2000-04-28	07:24:08.8	53.80	91.01	9.2	3.5	124.6	Abakan-1
2000-05-04	08:13:32.1	54.12	86.26	8.3	3.1	124.3	Krasniy
2000-05-04	11:30:14.0	54.21	87.11	9.3	3.6	210.0	Taldinsky
2000-05-06	08:21:30.2	53.66	87.86	8.6	3.3	-	Kzsky
2000-05-06	08:26:56.2	54.33	86.82	9.1	3.5	236.8	Krakansky
2000-05-06	08:32:47.4	53.51	87.47	8.3	3.1	-	Kltansky
2000-05-06	09:34:51.5	53.73	91.12	8.6	3.3	-	Abakan-1
2000-05-06	11:01:30.5	54.10	86.49	8.6	3.3	-	Krasniy Brod
2000-05-11	07:25:28.2	53.59	91.42	9.8	3.8	-	Abakan-2
2000-05-13	07:34:24.3	53.98	87.32	8.2	3.1	-	Erunakovski
2000-05-13	09:14:01.0	54.29	85.87	8.6	3.3	160.0	Bachatsky
2000-05-17	07:33:42.2	53.92	86.31	8.5	3.2	-	Kransky Brod
2000-05-17	08:15:50.7	53.59	87.74	8.7	3.3	172.6	Sibirginsky
2000-05-17	08:18:02.1	53.52	87.36	8.9	3.4	-	Kaltansky
2000-05-17	08:30:12.8	53.78	88.35	8.4	3.2	-	Olzherassky
2000-05-17	09:47:11.7	53.55	87.35	7.2	2.6	-	Kaltansky
2000-05-18	06:50:20.7	53.56	91.48	9.0	3.5	-	Abakan-2
2000-05-18	06:57:48.4	54.15	86.24	8.6	3.3	142.9	Bachatsky
2000-05-18	07:22:18.9	53.94	86.41	7.4	2.7	-	Krasniy Brod
2000-05-19	07:48:03.9	53.52	87.83	8.5	3.2	246.4	Sibirginsky
2000-05-19	08:22:41.9	53.95	86.54	8.1	3.0	-	Krasniy Brod
2000-05-19	09:19:46.1	54.05	86.35	8.7	3.3	180.0	Krasniy Brod
2000-05-20	09:23:22.8	54.07	87.46	8.7	3.3	-	Erunakovsky
2000-05-23	06:33:51.9	54.06	86.31	7.6	2.8	-	Krasniy Brod
2000-05-23	07:44:37.7	53.74	87.78	8.0	3.0	102.9	Mezhdurechensky
2000-05-24	08:40:45.9	53.68	87.85	9.3	3.6	152.8	Mezhdurechensky
2000-05-25	06:11:56.3	53.55	87.40	8.4	3.2	-	Kaltansky
2000-05-25	07:19:38.4	53.67	87.72	8.8	3.4	153.7	Sibirginsky
2000-05-25	07:39:15.2	54.04	86.31	8.3	3.1	-	Krasniy Brod
2000-05-26	07:27:55.0	54.03	86.35	8.2	3.1	-	Krasniy Brod
2000-05-26	07:47:52.5	54.61	86.46	9.2	3.5	106.3	Karansky
2000-05-26	09:14:45.4	53.75	91.10	10.0	3.9	-	Abakan-1
2000-05-29	07:32:52.3	53.69	87.42	8.6	3.3	114.2	Kalkatansky

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Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Energ (K)	Magnitude (m_b)	Yield (ton)	Location name
2000-05-29	08:37:07.8	54.14	87.12	8.6	3.3	116.0	Taldinsky
2000-06-01	08:30:26.9	54.46	86.36	9.1	3.5	-	Karansky
2000-06-01	09:08:24.2	53.72	91.04	8.8	3.4	-	Abakan-1
2000-06-05	08:30:20.9	54.03	86.45	7.9	2.9	117.8	Krasniy Brod
2000-06-05	08:54:22.6	54.79	87.11	8.6	3.3	-	Mohovsky
2000-06-08	07:34:17.5	53.82	88.15	8.9	3.4	192.2	Olzherassky
2000-06-10	07:31:13.2	54.02	86.46	7.4	2.7	-	Krasniy Brod
2000-06-10	07:53:22.4	54.10	86.88	8.3	3.1	123.5	Taldinsky
2000-06-10	10:02:32.3	54.13	87.17	9.4	3.6	-	Taldinsky
2000-06-15	04:33:28.9	54.32	86.78	8.8	3.4	-	Karakansky
2000-06-15	08:05:49.9	54.58	86.45	9.0	3.5	160.0	Karakansky
2000-06-16	06:03:12.4	54.05	86.49	8.3	3.1	-	Krasniy Brod
2000-06-16	08:44:04.9	53.76	91.01	9.5	3.7	-	Abakan-1
2000-06-16	08:56:22.2	52.11	86.64	7.4	2.7	261.8	-
2000-06-17	07:02:16.8	54.28	86.19	7.9	2.9	-	Bachatsky
2000-06-17	07:29:01.4	53.76	86.79	7.6	2.8	127.8	-
2000-06-17	10:44:52.7	54.23	86.29	8.5	3.2	-	Krasniy Brod
2000-06-17	10:54:09.5	54.18	86.29	9.1	3.5	-	Krasniy Brod
2000-06-19	07:09:20.9	54.07	86.42	8.5	3.2	130.9	Krasniy Brod
2000-06-19	07:24:59.9	54.10	86.39	8.4	3.2	-	Krasniy Brod
2000-06-19	09:06:13.6	54.15	86.41	9.3	3.6	-	Krasniy Brod
2000-06-19	10:14:12.6	54.18	86.39	9.0	3.5	-	Krasniy Brod
2000-06-20	07:27:46.0	54.02	86.58	8.3	3.1	162.0	Krasniy Brod
2000-06-21	06:43:13.9	53.60	87.80	8.9	3.4	-	Sibirginsky
2000-06-21	07:41:32.0	54.06	86.51	8.2	3.1	-	Krasniy Brod
2000-06-21	07:54:54.4	53.58	87.89	8.8	3.4	114.1	Kazsky
2000-06-21	09:16:18.5	53.73	91.08	8.8	3.4	-	Abakan-1
2000-06-21	12:21:15.0	54.10	86.48	8.6	3.3	-	Krasniy Brod
2000-06-22	07:26:28.3	53.65	87.75	8.8	3.4	100.1	Sibirginsky
2000-06-22	07:34:48.7	54.05	86.51	7.9	2.9	-	Krasniy Brod
2000-06-22	08:06:13.0	54.39	86.67	8.7	3.3	-	Karakansky
2000-06-23	06:39:10.0	53.58	87.36	8.2	3.1	128.0	Kaltansky
2000-06-23	10:27:19.6	54.06	87.42	8.8	3.4	-	Erunakovsky
2000-06-23	10:44:49.4	54.19	86.40	8.5	3.2	-	Krasniy
2000-06-27	11:48:42.0	53.48	91.60	9.1	3.5	124.5	Abakan-2
2000-06-29	04:01:12.6	53.53	91.45	8.6	3.3	-	Abakan-2
2000-06-30	10:35:32.5	54.15	87.22	9.1	3.5	106.6	Taldinsky
2000-07-02	12:02:06.3	53.72	91.03	9.1	3.5	-	Abakan-1
2000-07-07	07:13:56.7	53.75	91.13	9.3	3.6	186.7	Abakan-1
2000-07-10	04:07:23.4	53.57	91.32	8.6	3.3	-	Abakan-2
2000-07-13	07:23:53.2	54.09	87.29	9.2	3.5	113.4	Taldinsky
2000-07-14	07:19:12.4	53.75	91.01	9.8	3.8	147.7	Abakan-1
2000-07-28	12:08:28.7	53.73	91.03	9.0	3.5	-	Abakan-1
2000-08-02	10:51:15.8	54.16	87.19	8.9	-	-	Taldansky
2000-08-03	08:01:52.1	53.68	91.58	8.9	2.9	126.5	Abakan-2
2000-08-04	08:28:59.6	53.76	91.07	9.2	2.7	166.6	Abakan-1
2000-08-10	08:36:23.8	53.74	91.02	8.6	2.6	-	Abakan-1
2000-08-17	08:31:44.3	54.44	86.85	8.6	2.8	111.2	Karansky

continued next page

Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Energ (K)	Magnitude (m_b)	Yield (ton)	Location name
2000-08-18	12:34:48.5	54.58	86.37	9.5	3.3	191.0	karansky
2000-08-23	04:31:17.4	53.60	87.76	9.0	2.8	118.5	Sibirginsky
2000-08-23	11:28:54.8	54.31	86.79	9.0	3.3	-	Karakansky
2000-08-25	06:00:10.7	53.77	91.09	8.9	2.7	224.6	Abakan-1
2000-09-06	07:55:36.7	53.82	88.14	8.8	2.9	172.4	Olzherassky
2000-09-06	08:39:01.0	53.40	91.47	8.6	3.0	148.3	Abakan-2
2000-09-13	11:52:07.6	53.72	91.57	9.4	3.2	101.2	Abakan-2
2000-09-15	06:12:22.5	54.15	87.23	9.4	3.2	151.7	Taldinsky
2000-09-19	07:31:11.5	53.78	91.12	9.9	3.2	-	Abakan-1
2000-09-28	10:21:38.1	54.24	86.78	9.0	3.1	-	Karakansky
2000-10-04	06:55:12.8	53.72	90.99	8.9	2.8	224.7	Abakan-1
2000-10-05	06:21:10.9	53.79	91.11	8.7	-	-	Abakan-1
2000-10-06	07:33:27.6	53.63	91.46	9.6	3.1	158.5	Abakan-2
2000-10-12	07:37:33.6	53.69	91.07	8.8	-	200.9	Abakan-1
2000-10-13	07:16:20.8	54.16	87.26	9.0	-	-	Taldansky
2000-10-17	08:58:29.7	53.55	91.43	9.1	-	144.8	Abakan-2
2000-10-21	11:57:07.8	53.96	87.36	8.7	2.9	-	Erunakovski
2000-10-26	07:23:55.8	53.50	87.32	8.9	2.7	132.9	Kaltansky
2000-10-27	07:14:05.6	53.69	91.07	9.7	3.4	-	Abakan-1
2000-10-30	08:21:04.5	54.15	87.27	9.2	3.0	196.9	Taldansky
2000-10-30	08:42:04.5	53.53	91.47	8.6	2.7	139.5	Abakan-2
2000-11-03	09:56:02.2	53.99	87.40	9.0	3.0	241.1	Erunkovsky
2000-11-04	10:20:13.1	53.71	91.05	9.0	3.0	126.2	Abakan-1
2000-11-04	10:22:29.0	53.61	91.48	9.0	3.1	184.4	Abakan-2
2000-11-05	07:07:11.3	54.42	86.86	9.1	3.1	-	Karakansky
2000-11-10	09:06:10.2	53.74	91.07	9.1	-	115.2	Abakan-1
2000-11-15	12:26:19.2	54.10	87.20	8.8	2.9	-	Taldansky
2000-11-16	08:43:37.5	54.33	86.72	8.9	-	103.7	Karakansky
2000-11-17	07:57:21.0	53.53	87.39	8.6	2.7	153.8	Kaltansky
2000-11-18	10:37:56.3	53.97	87.40	8.6	-	168.9	Erunakovski
2000-11-24	09:25:28.7	54.08	87.19	9.3	3.1	-	Taldinsky
2000-11-26	04:59:05.1	52.95	87.98	9.2	3.0	690.0	Sheregeshsky
2000-12-07	08:52:56.4	53.75	91.08	10.0	-	146.2	Abakan-1
2000-12-09	07:56:44.7	53.74	91.04	9.1	-	-	Abakan-1
2000-12-14	09:33:57.4	53.66	87.95	8.8	3.0	141.4	Mezhdurensky
2000-12-16	09:10:16.6	53.28	91.46	8.8	2.7	136.3	Abakan-2
2000-12-22	09:05:25.1	53.70	91.07	8.9	-	153.0	Abakan-1
2000-12-25	11:13:45.2	54.13	87.23	9.0	2.9	-	Taldinsky
2000-12-26	09:35:33.9	54.37	86.85	8.7	-	-	Karakansky
2000-12-27	08:18:20.9	53.77	90.97	9.1	2.9	190.5	Abakan-1
2000-12-29	09:05:05.2	53.74	91.04	9.0	2.8	114.8	Abakan-1
2000-12-30	09:12:53.4	54.20	87.19	9.3	-	195.0	Taldinsky

[1] $m_b = 0.46K - 0.64$ [Khalturin et al., 1998]
* indicates events associated in seismic data at ELT station.

Table 4. List of earthquakes in Altay-Sayan during February–June, 1999

Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Depth (km)	Magnitude (m_b)
1999-02-04	20:34:33.5	52.36	92.33	15	2.4
1999-02-06	15:42:34.4	50.65	97.29	15	3.1
1999-02-08	17:56:02.1	49.38	94.90	15	4.1
1999-02-14	00:52:18.6	46.92	91.62	15	3.3
1999-02-15	13:48:20.2	51.11	98.12	15	2.8
1999-02-21	17:45:03.1	51.19	90.13	15	2.7
1999-02-23	08:43:18.2	46.31	90.72	15	3.4
1999-02-23	12:07:18.0	46.40	83.70	15	3.0
1999-02-24	23:17:55.4	50.51	87.48	15	2.5
1999-02-26	13:48:41.6	46.42	95.96	15	4.0
1999-03-05	15:37:24.7	51.21	98.18	15	3.0
1999-03-08	17:08:30.0	48.20	80.20	15	3.0
1999-03-09	15:29:38.7	49.26	96.34	15	2.8
1999-03-12	15:26:40.0	47.70	82.80	15	3.1
1999-03-15	02:37:12.4	49.95	91.85	15	3.2
1999-03-23	16:45:31.0	49.20	76.90	15	3.2
1999-03-27	18:35:49.4	49.22	92.18	15	4.4
1999-03-28	23:56:01.0	48.93	92.23	15	3.0
1999-04-02	19:14:36.0	54.30	97.00	15	2.6
1999-04-05	16:01:17.1	50.78	92.72	15	2.4
1999-04-07	14:36:08.9	49.88	93.02	15	2.7
1999-04-12	18:56:31.1	51.65	96.10	15	3.4
1999-04-14	00:56:23.5	49.01	92.20	15	3.4
1999-04-14	12:44:12.0	47.60	79.70	15	3.3
1999-04-23	22:28:47.0	44.60	76.50	15	3.3
1999-04-26	14:43:47.0	51.70	101.40	15	3.2
1999-05-11	12:06:48.5	54.87	93.86	15	2.9
1999-05-12	23:10:49.0	51.46	88.54	15	3.1
1999-05-19	10:44:21.3	50.78	97.83	15	3.2
1999-05-19	14:18:02.5	48.58	84.43	15	3.6
1999-05-21	07:49:03.4	51.80	94.05	15	3.0
1999-05-29	23:25:15.0	48.30	102.70	15	3.5
1999-05-31	20:39:00.0	47.40	82.80	15	2.8
1999-06-05	00:58:42.7	46.24	96.52	15	3.2
1999-06-05	10:55:36.9	50.66	93.18	15	2.6
1999-06-06	01:13:22.4	51.36	93.54	15	2.8
1999-06-08	13:35:22.3	50.11	91.60	15	3.1
1999-06-08	17:16:45.7	49.12	89.23	15	3.4
1999-06-08	21:28:19.6	49.16	89.24	15	3.4

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Date yr-mo-dd	Time hh:mm:ss	Lat (°N)	Lon (°E)	Depth (km)	Magnitude (m_b)
1999-06-10	04:23:04.5	51.81	93.94	15	3.5
1999-06-11	22:25:42.0	46.00	85.40	15	3.1
1999-06-11	22:43:39.0	46.00	85.40	15	3.3
1999-06-12	15:05:37.4	47.73	92.35	15	3.2
1999-06-14	13:56:59.7	52.04	98.74	15	2.7
1999-06-15	08:12:39.8	48.81	89.06	15	2.6
1999-06-16	17:28:07.5	51.61	92.80	15	3.6
1999-06-17	13:26:44.0	45.50	86.20	15	3.5
1999-06-18	00:42:12.6	49.45	90.22	15	3.6
1999-06-18	05:43:38.1	46.98	97.72	15	3.7
1999-06-18	12:54:37.0	45.00	79.40	15	3.4
1999-06-19	03:17:12.5	51.59	94.60	15	2.9

* indicates events associated at ELT station.

Section 4

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